

MINISTRY OF HIGHER EDUCATION, SCIENCE AND INNOVATION
OF THE REPUBLIC OF UZBEKISTAN

KARSHI STATE UNIVERSITY

ABSTRACTS

OF THE INTERNATIONAL SCIENTIFIC AND
PRACTICAL CONFERENCE

“APPLIED MATHEMATICS,
DIGITAL TRANSFORMATION AND
ARTIFICIAL INTELLIGENCE:
CURRENT ISSUES AND
PROSPECTS”



KARSHI, UZBEKISTAN



JUNE 5–6, 2026



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AI

$$\int_a^b f(x) dx \quad \lim_{x \rightarrow 0} \frac{\sin x}{x} = 1$$

$$\sum_{n=1}^{\infty} \frac{1}{n^2} = k \frac{\partial u}{\partial t}$$

$$e^{i\pi} + 1 = 0$$

$$\sum_{n=0}^{\infty} \frac{(ax)^n}{n!}$$

$$y = \ln x \quad \int_a^b f(x) dx$$



**O‘ZBEKISTON RESPUBLIKASI
OLIY TA’LIM, FAN VA INNOVATSIYALAR VAZIRLIGI
QARSHI DAVLAT UNIVERSITETI
“AMALIY MATEMATIKA, RAQAMLI TRANSFORMATSIYA VA SUN’IY
INTELLEKT:
ZAMONAVIY MUAMMOLAR VA ISTIQBOLLAR”**

**XALQARO ILMIY-AMALIY ANJUMAN
TEZISLAR TO‘PLAMI**

QARSHI, 2026-YIL 5-6- IYUN



**МИНИСТЕРСТВО ВЫСШЕГО ОБРАЗОВАНИЯ, НАУКИ И
ИННОВАЦИЙ РЕСПУБЛИКИ УЗБЕКИСТАН
КАРШИНСКИЙ ГОСУДАРСТВЕННЫЙ УНИВЕРСИТЕТ**

**ТЕЗИСЫ ДОКЛАДОВ
МЕЖДУНАРОДНОЙ НАУЧНО-ПРАКТИЧЕСКОЙ КОНФЕРЕНЦИИ**

**«ПРИКЛАДНАЯ МАТЕМАТИКА, ЦИФРОВАЯ ТРАНСФОРМАЦИЯ И
ИСКУССТВЕННЫЙ ИНТЕЛЛЕКТ:
СОВРЕМЕННЫЕ ПРОБЛЕМЫ И ПЕРСПЕКТИВЫ»**

КАРШИ, 5–6 ИЮНЯ 2026 ГОДА



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“Amaliy matematika, raqamli transformatsiya va sun’iy intellekt: zamonaviy muammolar va istiqbollar” Xalqaro ilmiy-amaliy anjuman tezislar to‘plami. 2026-yil 5-6- iyun. Qarshi: “ART-MATBAA-DESIGN” nashriyoti, 2026. 697 bet

Ushbu to‘plamda **“Amaliy matematika, raqamli transformatsiya va sun’iy intellekt: zamonaviy muammolar va istiqbollar”** Xalqaro ilmiy –amaliy anjuman ishtirokchilarining tezislari keltirilgan. Anjuman kun tartibiga kiritilgan masalalar dolzarb bo‘lib, u yalpi ma’ruzalar va amaliy matematika, raqamli transformatsiya va sun’iy intellektning zamonaviy muammolari, matematik modellashtirish, hisoblash va diskret matematika, matematik analiz, differensial tenglamalar, raqamlashtirish va zamonaviy dasturlash usullari, neyron tarmoqlar va chuqur o‘rganish, mashinali o‘rgatish va intellektual algoritmlar, ta’limda sun’iy intellekt, tabiiy tilni qayta ishlash kabi sho‘balardan tashkil topgan. To‘plam matematika, amaliy matematika va axborot texnologiyalari sohasi mutaxassislari, ilmiy tadqiqotchilar, professor-o‘qituvchilar, doktorantlar, magistrlar va talabalar uchun mo‘ljallangan.

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Mas’ul muharrir: dotsent O.R. Djabbarov, dotsent Sh.R. Davronovlar umumiy tahriri ostida
Maqolalarda keltirilgan ma’lumotlarning haqqoniyligi uchun mualliflar mas’uldir.

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KIRISH SO‘ZI

Assalomu alaykum hurmatli anjuman ishtirokchilari!

“Amaliy matematika, raqamli transformatsiya va sun’iy intellekt: zamonaviy muammolar va istiqbollari” mavzusiga bag‘ishlangan xalqaro anjuman o‘tkazilishi munosabati bilan Qarshi davlat universiteti jamoasi va shaxsan o‘z nomidan tabriklashga ruxsat etasiz. Bugungi anjuman O‘zbekiston Respublikasi Oliy ta’lim, fan va innovatsiyalar vazirligining 2026-yil 16-yanvardagi 11-son buyrug‘i bilan tasdiqlangan O‘zbekiston Respublikasining 2026-yilda respublika va xalqaro miqyosida o‘tkaziladigan ilmiy va ilmiy – texnik tadbirlar rejasi asosida o‘tkazilmoqda.

Mamlakatimizda keying yillarda fan va ta’limni rivojlantirishga, yoshlarning chuqur bilim olishiga munosib sharoit yaratishga katta e’tibor berilmoqda. O‘zbekiston Respublikasi Prezidentining fan va ta’lim tizimlarini rivojlantirishga qaratilgan bir qator Farmonlarga va Qarorlari qabul qilindi va amalga oshirilmoqda. 2019-yil 8-oktabrda “O‘zbekiston Respublikasi oliy ta’lim tizimini 2030 yilgacha rivojlantirish konsepsiyasini tasdiqlash to‘g‘risida”gi Farmon e’lon qilindi.

O‘zbekiston Respublikasi Prezidentining 2020-yil 7-maydagi PQ-4708-sonli “Matematika sohasidagi ta’lim sifatini oshirish va ilmiy-tadqiqotlarni rivojlantirish chora-tadbirlari” to‘g‘risida qarorida matematika sohasidagi ilmiy-tadqiqotlarni ishlab chiqarish va ta’lim bilan uzviy bog‘liqligini ta’minlash, amaliy matematikani rivojlantirish va iqtisodiyot tarmoqlaridagi muammolarni modellashtirish asosida matematik yechimlarni ishlab chiqish kabi masalalarga alohida e’tibor qaratilgan.

2020-yil 6-oktabrda “Axborot texnologiyalari sohasida ta’lim tizimini yanada takomillashtirish, ilmiy tadqiqotlarni rivojlantirish va ularni IT-industriya bilan integratsiya qilish chora-tadbirlari to‘g‘risida”gi PQ-4851 qarori e’lon qilindi. Qarorda axborot texnologiyalari sohasidagi kadrlarni tayyorlash tizimini takomillashtirish “Raqamli O‘zbekiston — 2030” strategiyasini muvaffaqiyatli amalga oshirish, raqamli texnologiyalarni rivojlantirish va aholining kundalik hayotiga keng joriy etishni ta’minlashning muhim shartlaridan biri ekanligi ko‘rsatib o‘tilgan.

Anjuman kun tartibiga kiritilgan masalalar dolzarb bo‘lib, u yalpi ma’ruzalar va amaliy matematika, raqamli transformatsiya va sun’iy intellektning zamonaviy muammolari, matematik modellashtirish, hisoblash va diskret matematika, matematik analiz, differensial tenglamalar, raqamlashtirish va zamonaviy dasturlash usullari, neyron tarmoqlar va chuqur o‘rganish, mashinali o‘rgatish va intellektual algoritmlar, ta’limda sun’iy intellekt, tabiiy tilni qayta ishlash kabi sho‘balardan tashkil topgan.

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Qadrlı hamkasblar! Anjumanning samarali o‘tishini, uning ishtirokchilariga mustahkam sog‘liq, ilm-fan va butun mamlakat farovonligi yo‘lida ulkan ijodiy muvaffaqiyatlar tilayman.

Nabiyev D.X.

Qarshi davlat universiteti rektori

1-SHO'BA. MATEMATIK MODELLASHTIRISH

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПРОСТРАНСТВЕННОЙ ДИНАМИКИ БИОЛОГИЧЕСКИХ ПОПУЛЯЦИЙ В НЕДИВЕРГЕНТНОЙ ФОРМЕ

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Аннотация. В данной работе исследуется квазилинейное уравнение реакции–диффузии, описывающее процессы пространственного распространения биологической популяции. Рассматривается задача Коши для нелинейного параболического уравнения с обобщённой диффузией типа p -лапласиана и нелинейным источником. Получено преобразование, приводящее исходное уравнение к более удобному виду, что позволяет построить автомодельные решения. Исследованы основные свойства решений, включая конечную скорость распространения, ограниченность и оценку массы. Установлены условия глобальной разрешимости задачи, а также рассмотрены режимы затухания и неограниченного роста решений. Полученные результаты могут быть использованы при математическом моделировании процессов динамики популяций и распространения биологических систем.

Введение.

Настоящая работа посвящена исследованию задачи Коши для квазилинейного уравнения реакции–диффузии с обобщённой нелинейной диффузией и источником логистического типа. Основное внимание уделяется построению автомодельных решений, позволяющих существенно упростить анализ исходной задачи, а также изучению качественных свойств решений.

Практическая значимость полученных результатов заключается в возможности их применения для моделирования динамики биологических популяций, распространения эпидемий и других процессов в нелинейных средах.

Структура работы следующая. В первом разделе формулируется постановка задачи и приводятся основные преобразования. Во втором разделе исследуются автомодельные решения. В третьем разделе изучаются качественные свойства решений и формулируются основные теоремы.

В настоящей работе исследуются в области $Q = \{(t, x): 0 < t < T, x \in R^N\}$ следующая задача

$$Lu = -\frac{\partial u}{\partial t} + u^n \nabla (Bu^{m-1} |\nabla u^k|^{p-2} \nabla u) + \gamma u(1 - u^\beta), \quad (1)$$

$$u|_{t=0} = u_0(x) \geq 0, x \in R^N \quad (2)$$

Данное уравнение представляет собой квазилинейное уравнение реакции–диффузии, описывающее процессы пространственного распространения популяции. Здесь $B > 0, n, m, k \geq 1, p \geq 2, \beta \geq 0$ - положительные вещественные числа, γ -коэффициент роста, $u = u(t, x) \geq 0$ искомое решение, где $u(t, x)$ плотность популяции среды в момент $t > 0$ в точке $x \in R$.

Уравнение (1) в случае $m=1, p=2, \beta = 1, n = 0$ было предложено Фишером в качестве детерминистической версии стохастической модели распространения благоприятного гена в диплоидной популяции, которое уравнение принимает вид:

$$\frac{\partial u}{\partial t} = B \Delta u + \gamma u(1 - u)$$

А так же численные решения уравнения при $\gamma(t) = 1, p=2$ или $m=1, n = 0$ изучено ранее другими авторами [2-4].

Это модель в частном случае, когда $k=1, p=2, n=0$, была предложена в работах [5], они показали, что фронт распространения вспышки локализован в каждый момент времени

на конечном носителе, что отличается от волны Колмогорова-Петровского-Пискунова. Изучена возможность возникновения стационарных и неоднородных по пространству решений. Сформулировано уточнение принципа Гаузе для пространственно распределенных конкурирующих систем.

Сделаем замену следующего вида

$$u(t, x) = e^{\gamma t} w(\tau(t), x) \quad (3)$$

где $\tau = \tau(t) = \int_0^t e^{-\gamma(n+m+k(p-2)-1)s} ds$ новая временная переменная, которая приведёт (1) к виду:

$$\begin{aligned} \frac{\partial w}{\partial \tau} &= w^n \nabla (B w^{m-1} |\nabla w^k|^{p-2} \nabla w) - a_1 \tau^b \gamma w^{\beta+1}, \\ w|_{t=0} &= w_0(x) = u_0(x). \\ \text{где } a_1 \tau^b &= \gamma e^{[\beta-(n+m+(p-2)k)]\gamma t}, \quad a_1 = \frac{1}{\gamma(k(p-2)+m+n-1)}, \\ b &= \frac{\beta - (n+m+(p-2)k-1)}{n+m+(p-2)k-1}, \quad \beta = n+m+(p-2)k-1. \end{aligned} \quad (4)$$

Для получения автомодельного уравнения для уравнения (4) применим алгоритм нелинейного расщепления, согласно которому найдём сначала решение обыкновенного дифференциального уравнения $\frac{d\bar{v}}{d\tau} = -a_1 \tau^b \bar{v}^{\beta+1}$,

Тогда для $\bar{v}(\tau)$ имеем

$$\bar{v}(\tau) = (c + \frac{\beta a_1 \tau^{b+1}}{b+1})^{-\frac{1}{\beta}}, \quad T_0 > 0.$$

А затем решение уравнения (4) ищется в виде

$$w(t, x) = \bar{v}(\tau) v(\tau, x), \quad (5)$$

Подставляя (5) в (4) и выбирая $\tau(t)$ из (4), имеем:

$$\begin{aligned} \frac{d\bar{v}}{d\tau} v + \bar{v}(t) \frac{\partial w}{\partial \tau} \frac{d\tau}{dt} &= \bar{v}^{(n+m+k(p-2))} \nabla (B v^{m-1} |\nabla v^k|^{p-2} \nabla v) + \gamma \bar{v} v (1 - \bar{v}^\beta v^\beta); \\ \gamma \bar{v} (1 - \bar{v}^\beta) v + \bar{v}(t) \frac{\partial v}{\partial \tau} \frac{d\tau}{dt} &= \bar{v}^{(n+m+k(p-2))} \nabla (B v^{m-1} |\nabla v^k|^{p-2} \nabla v) + \gamma \bar{v} v (1 - \bar{v}^\beta v^\beta). \\ \bar{v}(t) \frac{\partial v}{\partial \tau} \frac{d\tau}{dt} &= \bar{v}^{k(p-2)+n+m} \nabla (B v^{m-1} |\nabla v^k|^{p-2} \nabla v) + \gamma \bar{v}^{\beta+1} v (1 - v^\beta) \end{aligned}$$

а функция $\tau = \tau(t)$ выбирается так

$$\begin{aligned} \tau(t) &= \int_0^t \bar{v}^{n+m+(p-2)k-1}(t) dt = \\ &= \begin{cases} \frac{t^{1-[\gamma(n+m+(p-2)k-1)]}}{(1-[\gamma(n+m+(p-2)k-1)])}, & \text{если } 1 - \gamma(n+m+(p-2)k-1) \neq 0, \\ \ln t, & \text{если } 1 - \gamma(n+m+(p-2)k-1) = 0, \\ t, & \text{если } \gamma(n+m+(p-2)k-1) = 1. \end{cases} \end{aligned}$$

Тогда для $v(\tau, x)$ получим уравнение

$$\frac{\partial v}{\partial \tau} = v^n \nabla (B v^{m-1} |\nabla v^k|^{p-2} \nabla v) + \gamma \bar{v}^{\beta-(k(p-2)+n+m-1)} v (1 - v^\beta) \quad (6)$$

где

$$\bar{v} = \begin{cases} \frac{1}{(1-[\gamma(n+m+(p-2)k-1)]\tau)}, & \text{если } 1 - (\gamma(n+m+(p-2)k-1)) > 0, \\ \gamma c^{-[\gamma(n+m+(p-2)k-1)]}, & \text{если } 1 - [\gamma(n+m+(p-2)k-1)] = 0. \end{cases} \quad (7)$$

При $\beta = (k(p-2) + n + m - 1)$

$$\frac{\partial v}{\partial \tau} = v^n \nabla (B v^{m-1} |\nabla v^k|^{p-2} \nabla v) + \gamma v (1 - v^\beta)$$

Как видно из последнего уравнения мы получили тот же уравнение, что и ранее рассмотренное. Это показывает инвариантность приведенного выше преобразования.

Рассмотрим теперь функцию

$$v(\tau, x) = f(\xi), \quad \xi = |x| \tau^{-1/p},$$

$$f(\xi) = (a \pm \xi^{p/(p-1)})^{\frac{p-1}{k(p-2)+m+n-1}} \quad (8)$$

Тогда подставляя (8) в (4) в случае $1 - [\gamma(n+m+(p-2)k-1)] > 0$, относительно $f(\xi)$ получится автомодельное уравнение:

$$L(f) = f^n \frac{d}{d\xi} (Bf^{m-1} \left| \frac{d(f^k)}{d\xi} \right|^{p-2} \frac{df}{d\xi}) + \frac{\xi}{p} \frac{df}{d\xi} + a_1(f - f^{\beta+1}) = 0,$$

$$a_1 = \frac{1}{[\gamma(n+m+(p-2)k-1)]}, \quad [\gamma(n+m+(p-2)k-1)] \neq 0$$

В работе доказаны следующие теоремы.

Теорема 1. Пусть выполняется условие: $\beta > n+m+(p-2)k-1+p/N$, тогда задача Коши (1)-(2) глобально разрешима и для обобщённого решения имеет место оценка $u(t, x) \leq z(t, x)_+$ в области $Q = \{(t, x): t > 0, x \in R^N\}$ если $u_0(x) \leq z(0, x)$.

Где
$$z(t, x) = e^{\gamma t} [T + t]^{\frac{N}{p+(k(p-2)+m+n-1)N}} \bar{f}(\xi),$$

$$\bar{f}(\xi) = (a - b\xi^{p/(p-1)})^{\frac{p-1}{k(p-2)+m+n-1}}, \quad b = (k(p-2) + n + m - 1)(1/p)^{1/(p-1)}.$$

Теорема 2. Если $\beta = [p - [n+m+(p-2)k-1]/(p-1) - 1]$, то уравнение (1) имеет следующее точное решение

$$u(t, x) = a(t)(f(t) - x^{\frac{p}{p-1}})^{\frac{p-1}{k(p-2)+n+m-1}}$$

где $a(t)$ и $f(t)$ находятся из решения: вычисляя производные функции $u(t, x)$ имеем

$$\frac{\partial u}{\partial t} = \frac{da}{dt} (f(t) - x^{\gamma})^{\gamma_1} + a(t)\gamma_1 \frac{df}{dt} (f(t) - x^{\gamma})^{\gamma_1-1} \quad (10)$$

Уравнение (4) переписывается в следующем виде:

$$\begin{aligned} \frac{\partial w}{\partial \tau} &= w^n \nabla (Bw^{m-1} |\nabla w^k|^{p-2} \nabla w) - a_1 \tau^b \gamma w^{\beta+1} \\ w^n \nabla (Bw^{m-1} |\nabla w^k|^{p-2} \nabla w) &= [a(t)]^{n+m+k(p-2)} B(f(\tau)) - r^\lambda)^{(m-1)\gamma_1} \end{aligned} \quad (11)$$

где $a_1 = \frac{1}{\gamma(k(p-2)+m+n-1)}$, $\gamma = p/(p-1)$, $\gamma_1 = (p-1)/(k(p-2)+m+n-1)$

Теорема 3. Пусть $0 < \beta < 1$. Тогда при достаточно больших начальных данных решение может стать неограниченным за конечное время:

$$\lim_{t \rightarrow T} u(t, x) = \infty$$

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MEMBRANE FOULING PROPERTIES IN THE PROCESS OF FILTRATION AND TRANSPORTATION IN A CYLINDRICAL POROUS FILTER

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Annotation. This work presents a numerical model of filtration, solute transport, adsorption, and membrane fouling in a cylindrical porous filter. The model combines Brinkman–Darcy hydrodynamics with advection–diffusion–reaction equations and Langmuir adsorption kinetics. Numerical simulations demonstrate the evolution of concentration polarization, osmotic pressure, porosity reduction, and membrane flux decline during filtration. The results show the strong influence of adsorption and particle deposition on filtration efficiency and membrane resistance.

The study of filtration and transport processes in porous media is important for many industrial and environmental applications, including water purification, chemical treatment, and filtration technologies. The behavior of the liquid in such systems is largely determined by its physical properties, which directly affects the flow dynamics and mass transfer mechanisms.

Studies [1–2] present mathematical and numerical models of filtration and transport processes in cylindrical porous filters based on the axisymmetric Brinkman–Darcy equations and advection–diffusion–reaction transport equations with Langmuir adsorption and LDF kinetics. The models incorporate porosity–permeability relations through the Kozeny–Carman equation, particle deposition effects, and conservative numerical schemes using finite difference and finite volume methods to analyze flow behavior, adsorption dynamics, and filtration efficiency in porous media.

A mathematical model and numerical algorithm were developed to study filtration of liquid and ionized solutions, taking into account flow rate variation, suspension concentration, cake layer formation, pressure growth, and particle deposition in filter pores. Numerical simulations showed that the barodiffusion coefficient, initial flow rate, and filter thickness strongly influence filtration efficiency, ion exchange, hydraulic resistance, and outlet concentration.[3]

This study develops an integrated mathematical model for processes occurring in an axially symmetric cylindrical porous filter. The model incorporates fluid flow and pressure fields, multicomponent advection–diffusion transport, adsorption based on LDF kinetics and the Langmuir isotherm, particle deposition leading to clogging, and membrane transport effects. The hydrodynamics are governed by the Brinkman–Darcy equations, the permeability–porosity relationship is represented using the Kozeny–Carman equation, and mass transfer is described through ADR equations. Membrane fouling is simulated through time-dependent porosity reduction, while permeation and mass exchange at the membrane surface are imposed through boundary conditions.

Below are the equations for a cylindrical porous filter.

Equations for hydraulics (Brinkman-Darcy):

$$\frac{1}{r} \frac{\partial(r u_r)}{\partial r} + \frac{\partial u_z}{\partial z} = 0, \quad (1)$$

$$-\frac{\mu}{\kappa(\varepsilon)} u_r + \mu \left(\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial u_r}{\partial r} \right) + \frac{\partial^2 u_r}{\partial z^2} - \frac{u_r}{r^2} \right) - \frac{\partial p}{\partial r} = 0, \quad (2)$$

$$-\frac{\mu}{\kappa(\varepsilon)} u_z + \mu \left(\frac{1}{r} \frac{\partial}{\partial r} \left(r \frac{\partial u_z}{\partial r} \right) + \frac{\partial^2 u_z}{\partial z^2} \right) - \frac{\partial p}{\partial z} = 0, \quad (3)$$

$$\kappa(\varepsilon) = \frac{\varepsilon^3 d_f^2}{180(1-\varepsilon)^2}. \quad (4)$$

For liquids, the viscosity is approximated as

$$\mu = a \cdot 10^{\frac{b}{T-c}}$$

Where again T is absolute temperature and a , b , and c are experimentally determined constants. For water, using the values $a = 2.414 \times 10^{-5} \text{ N} \cdot \text{s} / \text{m}^2$, $b = 247.8 \text{ K}$, and $c = 140 \text{ K}$ results in less than 2.5 percent error in viscosity in the temperature range of 0 C to 370 C (Touloukian et al.,1975).

For substance transport (for each $i=1,\dots,N$), the following equations (6) – (9) are expressed:

$$\frac{\partial(\varepsilon c_i)}{\partial t} + \nabla \cdot (u c_i) = \nabla \cdot (\varepsilon D_i \nabla c_i) - r_i^{bulk} - a_s r_i^{surf}, \quad (5)$$

$$\frac{\partial q_i}{\partial t} = k_{f,i} (q_i^* - q_i), \quad (6)$$

$$q_i^* = \frac{q_{i,max} b_i c_i}{1 + \sum_{j=1}^N b_j c_j}, \quad (7)$$

$$r_{i, surf} = \rho_s \frac{\partial q_i}{\partial t}. \quad (8)$$

The colmatation (optional, particle) equations (9)-(10) defined as follows.

$$\frac{\partial(\varepsilon c_p)}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} (r c_p u_r) + \frac{\partial}{\partial z} (c_p u_z) = \frac{1}{r} \frac{\partial}{\partial r} \left(r \varepsilon D_p \frac{\partial c_p}{\partial r} \right) + \frac{\partial}{\partial z} \left(\varepsilon D_p \frac{\partial c_p}{\partial z} \right) - k_{dep} c_p, \quad (9)$$

$$\frac{\partial \varepsilon}{\partial t} = - \frac{v_{dep}}{\rho_{dep}} k_{dep} c_p. \quad (10)$$

Membrane equations (if available below, $G_m \equiv G_{out}$) are:

$$J_i = (1 - \sigma_i) c_{i,avg} J_v - P_{s,i} \Delta c_i, \quad (12)$$

$$J_v = \frac{\Delta P}{\mu (R_m + R_c)}, \quad (13)$$

$$R_c = \alpha_c \delta_c, \quad (14)$$

$$\frac{\partial \delta_c}{\partial t} = \frac{J_v c_{p,m}}{\rho_c}. \quad (15)$$

Boundary and initial conditions

The computational domain is an axisymmetric cylindrical domain

$$\Omega = \{(r, z) : 0 \leq r \leq R, 0 \leq z \leq H\}. \quad (16)$$

To close the system of equations (1)-(8), the following boundary and initial conditions are specified.

At the filter inlet ($z=0$), a uniform axial flow of liquid and known concentrations of components are set:

$$u_z(r, 0) = u_{in}, \quad u_r(r, 0) = 0, \quad c_i(r, 0) = c_{i,in}, \quad i = 1, \dots, N. \quad (17)$$

Neumann's condition is used for pressure:

$$\left. \frac{\partial p}{\partial z} \right|_{z=0} = 0. \quad (18)$$

At the filter outlet ($z=H$), a fixed pressure is set, and for the remaining values, the conditions of zero longitudinal gradient are met:

$$p(r, H) = p_{out}, \quad \left. \frac{\partial u_z}{\partial z} \right|_{z=H} = J_v, \quad \left. \frac{\partial u_r}{\partial z} \right|_{z=H} = 0. \quad (19)$$

Axis of symmetry ($r = 0$): Due to the axisymmetric nature of the solution, the following conditions are satisfied:

$$u_r(0, z) = 0, \quad \left. \frac{\partial u_z}{\partial r} \right|_{r=0} = 0, \quad \left. \frac{\partial p}{\partial r} \right|_{r=0} = 0, \quad \left. \frac{\partial c_i}{\partial r} \right|_{r=0} = 0, \quad i = 1, \dots, N. \quad (20)$$

Side surface of the filter ($r = R$): On the side wall of the filter, the adhesion conditions for the velocity and the absence of diffusion flow of substances are set:

$$u_r(R, z) = 0, u_z(R, z) = 0, \left. \frac{\partial p}{\partial r} \right|_{r=R} = 0, \left. \frac{\partial c_i}{\partial r} \right|_{r=R} = 0, i = 1, \dots, N. \quad (21)$$

Membrane level (if applicable, G_m) boundary conditions

$$u_n = J_v \quad (22)$$

Initial conditions ($t = 0$): For a non-stationary problem, the initial conditions are given in the form:

$$u_r(r, z, 0) = u_{r,0}(r, z), u_z(r, z, 0) = u_{z,0}(r, z), p(r, z, 0) = p_0(r, z), \quad (23)$$

$$c_i(r, z, 0) = c_{i,0}, q_i(r, z, 0) = 0, i = 1, \dots, N, \varepsilon(r, z, 0) = \varepsilon_0(r, z), \delta_c(r, z, 0) = 0, \quad (24)$$

$$R_c(r, z, 0) = 0, J_v(r, 0) = J_{v,0}. \quad (25)$$

Initially, the filter is assumed to be clean, with no deposited particles and no adsorption saturation. Therefore, the cake thickness and additional hydraulic resistance are zero. The initial velocity and pressure fields are obtained from a steady-state solution of the hydrodynamic equations without membrane fouling. velocity and pressure fields are initialized by solving a stationary hydrodynamic problem.

When solving the above equations, exact analytical solutions lead to complex calculations and difficulties. Therefore, the results of numerical methods are considered tools for solving these equations. One of the most effective methods for applying numerical solutions is the finite difference method.

The results demonstrate the temporal evolution of membrane fouling, concentration polarization, osmotic pressure growth, and flux decline, showing that adsorption and particle deposition significantly reduce filtration efficiency over time.

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НЕКОТОРЫЕ ПРЯМЫЕ И ОБРАТНЫЕ ДИНАМИЧЕСКИЕ ЗАДАЧИ ДЛЯ ДВУХФАЗНЫХ СРЕД

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Аннотация: В работе обсуждаются прямые и обратные динамические задачи для двухфазных сред.

В настоящее время интерес к математическому описанию нестационарных неизотермических процессов в гетерофазных средах крайне высок. В первую очередь, он связан с необходимостью решения разнообразных технологических задач: описание гидродинамики различных суспензий, эмульсий, аэрозолей, гранулированных и сыпучих смесей и составов различной структуры, участвующих в производственных циклах; разработка новых гетерофазных сплавов, неоднородных и композитных материалов для промышленности и строительства; проектирование и эксплуатация сложных систем

охлаждения и теплообмена для энергетических и обрабатывающих предприятий. Кроме того, интерес к математическому моделированию гетерофазных сред возникает при рассмотрении разнообразных задач описания техногенных систем: моделирование процессов в нефтяных скважинах и приповерхностных пластах, оптимизация процессов добычи полезных ископаемых; а так же при описании эндогенных процессов и при решении связанных с ними задач геодинамики и рудообразования. К числу последних можно отнести задачи гидродинамического описания процессов эволюции различных типов мантийно-коровых флюидных систем (фильтрационных течений литосферных флюидов в проницаемых зонах, процессов конвективного теплопереноса в глубинных магматических очагах, динамики флюидных гидротермальных систем и т.д.), решение которых является необходимым этапом при описании динамики развития крупномасштабных рудообразующих структур в рамках единой согласованной модели эволюции системы, включающей верхнюю мантию, мантийную литосферу и земную кору [1; 2]. При математическом описании указанных геологических и технологических процессов и систем используются разнообразные математические модели гетерофазных, в частности, двухфазных, сред, где, в качестве основных объектов моделирования можно выделить: течения в пористых и гранулированных средах (хладагенты в системах охлаждения, течения грунтовых вод, процессы в прискваженных зонах, фильтрационные и конвективные течения литосферных флюидов), течения газожидкостных и двухжидкостных смесей (процессы в кипящих и пузырьковых жидкостях, гидротермальные потоки).

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ПРИМЕНЕНИЕ КОРРЕЛЯЦИОННОГО ПАРАМЕТРА ДЛЯ ЗАДАЧ СЕЙСМОДИНАМИКИ

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Аннотация

По данным различных сейсмических каталогов мира с помощью алгоритма нахождения аномалий K_{COR} (коэффициента парной корреляции нормированного крипекса Cr [1] и магнитуды M_s), предваряющих сильнейшие и умеренные ($M_s \geq 4.6$) землетрясения, показаны возможности достоверного исследования динамики состояния среды накануне этих событий.

Алгоритм сканирования каталогов анализирует события в границах «дальней зоны» влияния подготовки очага R_d . Предполагается, что радиус «ближней зоны» очага [2]:

$$R_b = 10^{M_s \cdot 0.33 - 0.61} \quad (1)$$

соответствует области влияния полей напряжения в поликристаллическом упругом материале и может быть принят за границу жесткого включения очага. Тогда за пределами этой границы, по-видимому, более активен процесс передачи гидростатического давления в вязкоупругой среде (распорное действие пластичного вещества, заполняющего уже

существующие разломы кристаллической среды [3]), при котором изменение локального кристаллического давления может распространяться на сотни-тысячи километров. Таким образом, оценку предельного размера R_d «дальней зоны» влияния очага можно получить на основе решения задачи о распределении напряжений в окрестности жесткого включения (будущего очага) в среде, находящейся в упругопластическом состоянии [4]. Сравнение скорости стремления напряжений к начальным значениям по мере удаления от включения в упругой и в упругопластической средах, согласно [4], дает оценки, пропорциональные $1/R^2$ и $1/R^D$, соответственно. При этом, оценки показателя D соответствует максимальной величине $D=1^{2/5}$ [4] и минимальная величина R_d соотносится с R_b как:

$$R_d = R_b^{2/D} = R_b^{2/1.4} \quad (2)$$

Исследование проводится с помощью геоинформационной системы GIS-ENDDB [5] на основе расчета R_d текущего события по формулам (1) и (2), выбора предваряющей сейсмичности в соответствующей круговой области и расчета для полученной выборки временных графиков параметра K_{COR} согласно алгоритму «с фиксированным в точке рассматриваемого события краем окна» [1].

По сильнейшим землетрясениям ($M_s \geq 8$) выявлено, что 7 из 11 событий глобального каталога IDC [6] и 10 из 22 - глобального каталога ВЛ [7] (Института Геофизики Китайской Академии Наук) предваряются в их R_d областях аномалиями $|K_{COR}| \geq 0.7$ длительностью от 25 дней до 3 лет.

При анализе умеренной сейсмичности учитывалось, что множества событий, представленных в различных каталогах, существенно различаются по времени, магнитуде и локализации, и их синхронизация затруднена. Это дает различающиеся оценки как по влиянию на сейсмичность внешних факторов (оцениваемому по усредненному тренду K_{COR} [8] и обнаружившему различные результаты в двух рассматриваемых каталогах, начиная с 2011 года), так и по состоянию среды накануне каждого землетрясения. Соотношение консолидации и пластичности сейсмогенной среды (оцениваемое с учетом знака аномалий K_{COR}) показывает в целом по миру $\sim 2/3$ для IDC и $1/3$ для ВЛ в пользу пластичного состояния зон подготовки событий. При этом, количество цепочек консолидации в этих каталогах приблизительно одинаково. Но только десятая часть из этого количества – это цепочки (и предваряемые ими события), представленные в обоих каталогах. Очевидно, что именно по этим землетрясениям можно проверить достоверность наших оценок, т.к. эти события зарегистрированы независимыми источниками, а наличие перед ними аномалий отрицательного знака по наборам данных независимых каталогов подтверждает универсальность предложенного метода, его объективность при определении физических параметров среды накануне землетрясения.

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ПЛОСКАЯ ВНЕШНЯЯ ЗАДАЧА НЕЙМАНА ДЛЯ ДАВЛЕНИЯ ВОЗНИКАЮЩАЯ В ГИДРОДИНАМИКЕ

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Аннотация: Рассматривается плоская внешняя задача Неймана для уравнения Лапласа возникающей гидродинамике. Доказана разрешимость рассмотренной задачи в весовом анизотропном пространстве Соболева.

Пусть $\Omega \subset R^2$ - односвязная область гладкой границей $\Gamma = \partial\Omega$, $0 \in \Omega$, $\Omega' = R^2 \setminus \Omega$ - внешность области. Следовательно, $B_{r_0} \subset \Omega \subset B_{r_1}$, где B_{r_0} и B_{r_1} круги радиуса r_0, r_1 соответственно. Границу круга будем обозначать $\Gamma_r = \partial B_r$. Далее без потери общности считаем, что $r_0 > 3$. В дальнейшем используем полярные координаты (r, φ) . При этом $\ln r > 1$, если $(x, y) \in B_{r_0}$. В частности, $\ln r > 1$, если $(x, y) \in \Omega'$.

Рассматриваем задачу Неймана во внешности Ω'

$$\Delta p = f, \quad p_\nu = g. \quad (1)$$

Нас будут интересовать классы $W_{1,1}^{1,2}(\Omega')$ и $W_{-1,-1}^{1,2}(\Omega')$. При этом опираемся на результаты для пространства $W_{0,0}^{1,2}(\Omega')$ [1]

$$\int_{\Omega'} \left(\frac{p^2}{r^2 \ln^2 r} + |\nabla p|^2 \right) dx dy < \infty.$$

Для первого пространства имеем

$$\int_{\Omega'} \left(\ln^2 r p^2 + r^2 \ln^2 r |\nabla p|^2 \right) dx dy < \infty.$$

Для второго пространства имеем

$$\int_{\Omega'} \left(\frac{p^2}{r^4 \ln^2 r} + \frac{|\nabla p|^2}{r^2 \ln^2 r} \right) dx dy < \infty.$$

Сначала рассматриваем однородную задачу

$$\Delta p = f, \quad (2)$$

$$p_\nu = g. \quad (3)$$

В докладе доказаны следующие утверждения:

Лемма 1. Ядро оператора Лапласа с условиями Неймана в пространстве $W_{1,1}^{1,2}(\Omega')$ содержит только $p(x, y) \equiv 0$.

Доказательство. Очевидно, что $W_{1,1}^{1,2}(\Omega') \subset W_{0,0}^{1,2}(\Omega')$. Ядро оператора Лапласа с условиями Неймана в пространстве $W_{0,0}^{1,2}(\Omega')$ состоит из констант. Но они не принадлежат пространству $W_{1,1}^{1,2}(\Omega')$.

Лемма 2. Ядро оператора Лапласа с условиями Неймана в пространстве $W_{-1,-1}^{1,2}(\Omega')$ трехмерно. Базис содержит три линейно независимых функции $p_0(x, y)$, $p_1(x, y)$, $p_2(x, y)$:

$$p_0(x, y) \equiv 1,$$

$$p_1(x, y) - r \cos \varphi \in W_{0,0}^{1,2}(\Omega'), \quad p_1(x, y) \sim r \cos \varphi, \quad r \rightarrow \infty,$$

$$p_2(x, y) - r \sin \varphi \in W_{0,0}^{1,2}(\Omega'), \quad p_2(x, y) \sim r \sin \varphi, \quad r \rightarrow \infty.$$

Теорема. Для разрешимости задачи (2), (3) в пространстве $W_{1,1}^{1,2}(\Omega')$ необходимо и достаточно, чтобы на границе Γ выполнялись условия ортогональности

$$g \perp 1, \quad g \perp p_1|_\Gamma, \quad g \perp p_2|_\Gamma.$$

При этом решение (если существует) единственно.

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ҚАНДЛИ ДИАБЕТДА ГЛЮКОЗА КОНЦЕНТРАЦИЯСИ ВА БИОАФАОЛ НУҚТАЛАРНИНГ БИОФИЗИК ПАРАМЕТРЛАРИ ЎРТАСИДАГИ БОҒЛИҚЛИКНИ МОДЕЛЛАШТИРИШ

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Аннотация: Жаҳонда қандли диабет (ҚД) касаллигида қон таркибидаги глюкоза миқдори тезкор (экспресс) тарзда ИРТ усуллари ёрдамида ноинвазив усуллари асосида глюкометр қурилмасини яратиш яратиш давр талабидир.. ҚДнинг пайдо бўлиши, танадаги биофаол нукталарда биофизик параметрлари ўзгариб кетиши натижасида меридианларда дисбаланс юзага келиши исботланган. ҚД касаллигида, муайян БФН (Тай-бай. Синг-гу. Шэнь-мэнь, Да-лин, Тай-си)ларнинг биофизик параметрларининг иабетик бемор қони таркибидаги глюкоза миқдори ошишига боғлиқ эканлигини манбалардан маълум. БФНдаги

ўзгаришлар билан касаллик ўртасидаги боғлиқлик жараёнини аниқлаш учун, математик моделлаштириш улули ёрдамида аниқлаш мумкин

Таянч иборалар: биофаол нуқталар, меридиан, дисбаланс, иглорефлексотерапия, корреляция коэффициентлари, модель,

Abstract: The need to develop a glucometer based on non-invasive methods for rapid (express) determination of blood glucose levels in diabetes mellitus (DM) is urgently needed worldwide. It has been proven that the development of DM is caused by changes in biophysical parameters at bioactive points on the body, leading to meridian imbalance. It is known from sources that in DM, the biophysical parameters of certain bioactive points (Tai Bai, Xing Gu, Shen Men, Da Lin, and Tai Xi) are associated with increased blood glucose levels in patients with diabetes. Mathematical modeling methods can be used to determine the relationship between changes in bioactive points and the disease.

Keywords: bioactive points, meridian, imbalance, acupuncture, correlation coefficients, model.

Манбалардан маълумки, инсон организми мураккаб тизим бўлиб, унда биофаол нуқта (БФН)лар тўплами мавжуд. Бу БФНдаги биофизик параметрларнинг инсон организмида пайдо бўлган касалликлар натижасида ўзгаришлар содир бўлиши илмий асосланган [1,2,3,4]. Инсон организмида касалланган органлар билан биргаликда касалланган БФН ҳосил бўлиши жараёни сабаблари манбалар [3,4]да етарлича талкин этилган. ҚДда иглорефлексотерапия (ИРТ)нинг биоўлчагич ускуналарини қўллаш натижасида касалланган БФНнинг пайдо бўлиши ва унинг биофизик параметрлари ўзгариб кетиши натижасида меридианларда дисбаланс юзага келиши исботланган. ҚД касаллиги мисолида бундай дисбаланс, муайян БФН (Тай-бай. Синг-гу. Шэнь-мэнь, Да-лин, Тай-си)ларнинг биофизик параметрларининг ўзгариши, ҳамда диабетик бемор қони таркибидаги глюкоза миқдори ошишига боғлиқ эканлигини манбалардан маълум. БФНдаги ўзгаришлар билан касаллик ўртасидаги боғлиқлик жараёнини аниқлаш учун, математик моделлаштириш улули ёрдамида аниқлаш мумкин[4]. Қон таркибидаги глюкоза даражасини БФНлардаги электр қаршиликлари миқдорларига боғлиқлигининг чизикли кўринишдаги модели қуйидаги кўринишда бўлади:

$$y = -6,14 - 0,0016x_1 + 0,0116x_2 - 0,0099x_3 + 0,021x_4 - 0,0572x_5 + 0,0021x_6 + 0,0443x_7 + 0,0075x_8 + 0,0086x_9 + 0,0669x_{10}. \quad (1)$$

(1) тенгламада қуйидаги белгилашлардан фойдаланилган:

x_1 – Тай-бай БФНнинг чап томонидан ўлчанган электр қаршилиги миқдори; x_2 – Тай-бай БФНнинг ўнг томонидан ўлчанган электр қаршилиги миқдори; x_3 – Да-лин БФНнинг чап томонидан ўлчанган электр қаршилиги миқдори; x_4 – Да-лин БФНнинг ўнг томонидан ўлчанган электр қаршилиги миқдори; x_5 – Синг-гу БФНнинг чап томонидан ўлчанган электр қаршилиги миқдори; x_6 – Синг-гу БФНнинг ўнг томонидан ўлчанган электр қаршилиги миқдори; x_7 – Тай-си БФНнинг чап томонидан ўлчанган электр қаршилиги миқдори; x_8 – Тай-си БФНнинг ўнг томонидан ўлчанган электр қаршилиги миқдори; x_9 – Шэнь-мэнь БФНнинг чап томонидан ўлчанган электр қаршилиги миқдори; x_{10} – Шэнь-мэнь БФНнинг ўнг томонидан ўлчанган электр қаршилиги миқдори.

Хулоса

Қондаги глюкоза миқдорини аниқлашда инсон танасида жойлашган БФНлардан олинган электр қаршилиги 95% эҳтимоллик билан боғланиш борлигини математик статистика усуллари тасдиқлади.

Қандли диабетни тасхислашда ва моделлаштиришда, муайян БФН (Тай-бай. Синг-гу. Шэнь-мэнь, Да-лин, Тай-си)лар адекватлиги ўз исботини топди.

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NUMERICAL MODELING OF A TWO-PARAMETER SINGULARLY PERTURBED BOUNDARY-VALUE PROBLEM USING THE SPECTRAL-GRID METHOD

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For solutions of two-parameter singular perturbed boundary value problems, there are usually two boundary layers in the solution domain. Therefore, the efficiency of existing methods for numerical modeling of problems of this type is sharply reduced. In this work, a spectral-grid method is presented, which allows solving problems of this type efficiently and with high accuracy.

Consider a two-parameter singular perturbed equation with small parameters in front of its second and first order derivatives:

$$-\varepsilon u''(x) + \mu u'(x) + u(x) = \cos(\pi x), x \in [0, 1]. \quad (1)$$

Let the equation have the following boundary conditions:

$$u(0) = u(1) = 0, \quad (2)$$

where ε and μ are small parameters. For the numerical modeling of differential equation (1) – (2), we use the spectral-grid method based on the first type of Chebyshev polynomials as a base function. Typically, the test function method is used to verify the approximation and accuracy order of any numerical method. According to this approach, an optional function $u_\varepsilon(x)$ satisfying boundary conditions (2) is chosen [1]. By putting it in equation (1), the function on the right side of the equation is defined. The problem under consideration is solved using the spectral-grid method, and the approximate solution is compared with the selected test function at the Chebyshev collocation nodes.

Solution Method

To numerically model problem (1)-(2), we present the algorithm of the spectral-grid method. For this purpose, on the integration interval $[\eta_0, \eta_l]$, a grid $\eta_0 < \eta_1 < \dots < \eta_N = \eta_l$ is introduced, which generates N grid subintervals of the form

$$[\eta_0, \eta_1], [\eta_1, \eta_2], \dots, [\eta_j, \eta_{j+1}], \dots, [\eta_{N-1}, \eta_N], j = 1, 2, \dots, N-1.$$

Differential equation (1) in each of these grid elements would look like this:

$$-\varepsilon \frac{d^2 u_j}{d\eta^2} + \mu \frac{du_j}{d\eta} + u_j(\eta) = f_j(\eta), j = 1, 2, \dots, N. \quad (3)$$

The boundary conditions (2) at the points η_0 and η_N are written as

$$u(\eta_0) = 0, \quad u(\eta_N) = 0. \quad (4)$$

At the interior nodes, the solution of equation (1) and its first-order derivative are required to be continuous. These conditions can be written in the following form:

$$u_j^{(t)}(\eta_j) = u_{j+1}^{(t)}(\eta_j), \quad t = 0, 1; \quad j = 1, 2, \dots, N-1. \quad (5)$$

Here, t – denotes the order of the derivative.

We represent the approximate solution $u_j(x)$ of problem (3) – (5) in the form of a truncated series of the first-kind Chebyshev polynomials. Then, each grid element $[\eta_j, \eta_{j+1}]$ is mapped onto the interval $[-1, 1]$ according to the following transformation:

$$\eta = \frac{m_j}{2} + \frac{l_j}{2}x, \quad m_j = \eta_j + \eta_{j+1}, \quad l_j = \eta_{j+1} - \eta_j, \quad j = 1, 2, \dots, N-1, \quad (6)$$

where $\eta \in [\eta_j, \eta_{j+1}]$, $x \in [-1, 1]$, $l_j - (j+1)$ is the length of the grid element. As a result, equation (3) takes the following form:

$$-\varepsilon \left(\frac{2}{l_j} \right)^2 \frac{d^2 u_j}{dx^2} + \mu \left(\frac{2}{l_j} \right) \frac{du_j}{dx} + u_j(x) = f_j(x), \quad j = 1, 2, \dots, N. \quad (7)$$

The boundary conditions (4) and the continuity conditions (5) are written in this form:

$$u_1(0) = 0, \quad u_N(+1) = 0, \quad \left(\frac{2}{l_j} \right)^t u_j^{(t)}(+1) = \left(\frac{2}{l_{j+1}} \right)^t u_{j+1}^{(t)}(-1), \quad t = 0, 1; \quad j = 1, 2, \dots, N-1, \quad (8)$$

where t – denotes the order of the derivative.

We represent the approximate solution of problem (7)-(8) and its right-hand side $f_j(x)$ on each grid element in the form of truncated series of the first-kind Chebyshev polynomials:

$$u_a^{(j)}(x) = \sum_{n=0}^{p_j} a_n^{(j)} T_n(x), \quad f_j \left(\bar{x}_l^{(j)} \right) = \sum_{n=0}^{p_j} b_n^{(j)} T_n(x_l^{(j)}), \quad \bar{x}_l^{(j)} = \frac{m_j}{2} + \frac{l_j}{2} x_l^{(j)}, \quad (9)$$

$$x_l^{(j)} = \cos \frac{\pi l}{p_j}, \quad l = 0, 1, \dots, p_j; \quad j = 1, 2, \dots, N.$$

Here, $u_a^{(j)}(x)$ is the approximate solution, $T_n(x)$ are the first-kind Chebyshev polynomials, $x_l^{(j)}$ are their collocation nodes, p_j denotes the number of polynomials used to approximate the solution on the j -th element, and $a_n^{(j)}$ are unknown coefficients.

For the known function $f_j(x)$, the coefficients $b_n^{(j)}$ in (9) are determined using the following inverse transformation:

$$b_n^{(j)} = \frac{2}{p_j c_n} \sum_{l=0}^{p_j} \frac{1}{c_l} f_j \left(\bar{x}_l^{(j)} \right) T_n(x_l^{(j)}), \quad n = 0, 1, 2, \dots, p_j, \quad (10)$$

where $c_0 = c_{p_j} = 2, c_m = 1 (m \neq 0, p_j); \quad j = 1, 2, \dots, N, \quad M = \sum_{j=1}^N (p_j + 1)$ is the total number of Chebyshev polynomials used to approximate the solution by the spectral-grid method, while N is the number of grid elements. Using representation (9), the derivatives of various orders of the approximate solution $u_a^{(j)}(x)$ can conveniently be computed by the following formulas:

$$u_a^{(j)}(y) = \sum_{n=0}^{p_j} a_n^{(j)} T_n(y),$$

$$u_a^{(1)}(y) = \sum_{n=0}^{p_j} a_n^{(1)} T_n(y), \quad a_n^{(1)} = \frac{2}{c_n} \sum_{\substack{q=n+1 \\ q+n \equiv 1 \pmod{2}}}^{p_j} q a_q, \quad n \geq 0, \quad (12)$$

$$u_a^{(2)}(y) = \sum_{n=0}^{p_j} a_n^{(2)} T_n(y), \quad a_n^{(2)} = \frac{2}{c_n} \sum_{\substack{q=n+2 \\ q \equiv n \pmod{2}}}^{p_j} q(q^2 - q^2) a_q, \quad n \geq 0.$$

To determine the unknowns $x^T = (a_0^{(1)}, a_1^{(1)}, \dots, a_{p_1}^{(1)}, a_0^{(2)}, a_1^{(2)}, \dots, a_{p_2}^{(2)}, \dots, a_0^{(N)}, a_1^{(N)}, \dots, a_{p_N}^{(N)})$, the formula $M = \sum_{j=1}^N (p_j + 1) = N(p_j + 1)$ is used, where the number of equations is also equal to $M = N(p_j + 1)$. In the resulting algebraic system, number of the principal equations corresponding to (7) is equal to $N(p_j - 1)$, to which two boundary conditions and $2(N - 1)$ the continuity conditions from (8) are added. The resulting system of algebraic equations can therefore be written in the matrix form:

$$Ax = b \quad (13)$$

where $b^T = (b_0^{(1)}, b_1^{(1)}, \dots, b_{p_1}^{(1)}, b_0^{(2)}, b_1^{(2)}, \dots, b_{p_2}^{(2)}, \dots, b_0^{(N)}, b_1^{(N)}, \dots, b_{p_N}^{(N)})$, x^T and b^T denotes the corresponding transposed vectors.

Table 1: Maximum absolute error of the spectral-grid method

		μ	$M = \sum_{j=1}^N (p_j + 1)$	B-spline method[1] Δ	Spectral-grid method				
					P_1	P_2	P_3	P_4	Δ
0 ⁻⁸	10 ⁻⁴	64	9.1 x 10 ⁻³	1	1	1	1	1	3.1 x 10 ⁻¹
				6	6	6	6	6	2.4 x 10 ⁻²
				2	8	8	2	2	5.5 x 10 ⁻³
				4	4	4	4	8	
		128	2.0 x 10 ⁻³	3	3	3	3	3	1.0 x 10 ⁻³
				2	2	2	2	4	2.9 x 10 ⁻⁷
				4	1	1	8	5	1.8 x 10 ⁻⁹
				8	6	6	6	6	
		256	5.2 x 10 ⁻⁴	5	8	8	8	6	6.0 x 10 ⁻¹²
				6	6	6	4	4	4.9 x 10 ⁻¹³
				4	4	3	3	3	8.5 x 10 ⁻¹³
				9	3	2	2	1	
				6	2	1	1	12	

As can be seen from the above table, for different values of the small parameters ε μ and the number of polynomials M, the maximum absolute error of the proposed spectral-grid method is significantly smaller than the obtained by the B-spline method. This demonstrates the efficiency and high accuracy of the spectral-grid method, namely that the optimal placement of Chebyshev polynomials on the grid elements ensures high accuracy while requiring fewer arithmetic operations.

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ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ ЗАДАЧИ АНОМАЛЬНОЙ ФИЛЬТРАЦИИ ЖИДКОСТИ В НЕОДНОРОДНОЙ ПОРИСТОЙ СРЕДЕ

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Аннотация. В данной работе исследована задача аномальной фильтрации жидкости в кусочно-неоднородной по проницаемости пористой среде. Для описания аномальности процесса используется дробная производная в законе Дарси и соответствующее уравнение пьезопроводности. При заданных начальных и граничных условиях задача решена численно методом конечных разностей. Оценено влияние изменения порядка дробной производной на распределение давления и скорость фильтрации жидкости.

В нефтяных месторождениях с тяжелыми нефтями часто наблюдается нарушение закона фильтрации. Наиболее характерным является нарушение равновесности закона, он становится неравновесным [1].

В [1] процессы неравновесной фильтрации анализировались на основе классических дифференциальных уравнений целочисленного порядка. Однако описание аномальных фильтрационных процессов, наблюдаемых во фрактальных пористых средах, с помощью дифференциальных уравнений целого порядка не обеспечивает достаточной адекватности. В последние годы значительно активизировались исследования по изучению аномальных процессов фильтрации на основе уравнений дробного порядка.

Уравнение фильтрации жидкости в одномерном случае, выведенное на основе аномального закона фильтрации [2], имеет вид

$$\mu\beta^* \frac{\partial p}{\partial t} = \frac{\partial}{\partial x} \left(k(x) \frac{\partial}{\partial x} \left(\frac{\partial^\alpha p}{\partial t^\alpha} \right) \right), \quad 0 < x < L, L = \text{const}, \quad (1)$$

где μ – динамический коэффициент вязкости, β^* – коэффициент упругоёмкости среды, t – время, p – давление, $k(x)$ – фрактальная кусочно-неоднородная проницаемость, $\alpha (0 \leq \alpha < 1)$ – порядок производной.

Среда состоит из трех зон одинаковой длины, но в каждой из них проницаемость $k(x)$ различна.

Начальное условие принимаем в виде:

$$p(0, x) = p_0 = \text{const}. \quad (2)$$

Граничные условия следующие:

$$p(t, 0) = p_c (1 + \sin(\omega \cdot t)), \quad p(t, L) = 0, \quad \omega = \text{const}, \quad \omega > 0, \quad p_c = \text{const}. \quad (3)$$

В точках разрыва проницаемости $x = \frac{L}{3}, \frac{2L}{3}$ давление и скорость фильтрации остаются непрерывными. Соответственно, принимаются следующие условия

$$p(t, x) \Big|_{x=\left(\frac{L}{3}\right)-0} = p(t, x) \Big|_{x=\left(\frac{L}{3}\right)+0}, \quad (4)$$

$$p(t, x) \Big|_{x=\left(\frac{2L}{3}\right)-0} = p(t, x) \Big|_{x=\left(\frac{2L}{3}\right)+0}, \quad (5)$$

$$\frac{k}{\mu} \frac{\partial^\alpha}{\partial t^\alpha} \left(\frac{\partial p}{\partial x} \right) \Big|_{x=\left(\frac{L}{3}\right)-0} = \frac{k}{\mu} \frac{\partial^\alpha}{\partial t^\alpha} \left(\frac{\partial p}{\partial x} \right) \Big|_{x=\left(\frac{L}{3}\right)+0}, \quad (6)$$

$$\left. \frac{k}{\mu} \frac{\partial^\alpha}{\partial t^\alpha} \left(\frac{\partial p}{\partial x} \right) \right|_{x=\left(\frac{2L}{3}\right)_0} = \left. \frac{k}{\mu} \frac{\partial^\alpha}{\partial t^\alpha} \left(\frac{\partial p}{\partial x} \right) \right|_{x=\left(\frac{2L}{3}\right)+0} . \quad (7)$$

Для решения задачи (1) – (7) использован метод конечных разностей. Отметим, что для простых условий задача анализирована в [3].

Некоторые результаты для давления и скорости фильтрации для двух трех значений α и нелинейных зависимостях $k(x)$ в зонах приведены на рис.1-2.

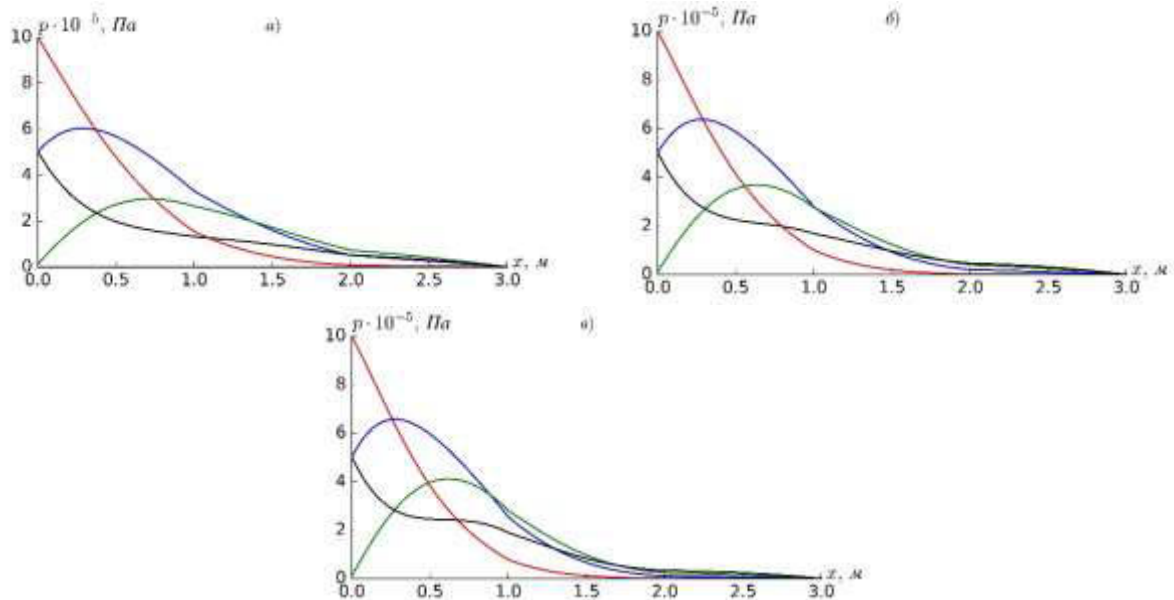


Рис.1. Профили давления при $\alpha = 0(a)$, $0.1(б)$, $0.15(в)$, $t = 170(—)$, $350(—)$, $500(—)$, $700(—)$ с.

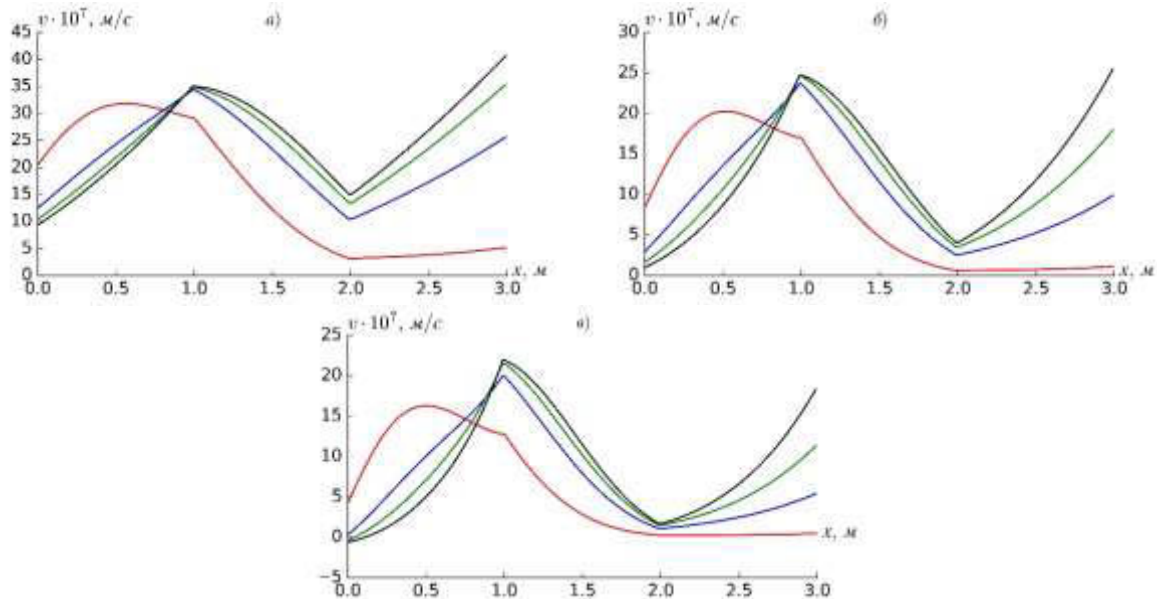


Рис.2. Профили скорости фильтрации при $\alpha = 0(a)$, $0.1(б)$, $0.15(в)$, $t = 170(—)$, $350(—)$, $500(—)$, $700(—)$ с.

Как видно из графиков, влияние α в различных зонах изменения $k(x)$ проявляется различным образом. можно увидеть падение давления с увеличением дробного порядка α и преломление на графиках при переходе из одной зоны в другую.

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ASYMPTOTIC BEHAVIOR AND ESTIMATE OF BLOW-UP SOLUTIONS OF A NONLINEAR PARABOLIC SYSTEM IN NON-DIVERGENCE FORM

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In this paper, we study the asymptotic behavior of self-similar solutions for a system of nonlinear parabolic equations in non-divergence form, representing the mathematical model of heat diffusion and combustion processes, and derive estimates for the subsolution.

$$\begin{cases} \frac{\partial u}{\partial t} = \frac{\partial}{\partial x} (u^{m_1-1} \frac{\partial u}{\partial x}) - e^{\alpha_1 t} v^{k_1} \\ \frac{\partial v}{\partial t} = \frac{\partial}{\partial x} (v^{m_2-1} \frac{\partial v}{\partial x}) - e^{\alpha_2 t} u^{k_2} \end{cases} \quad (1)$$

$$\begin{cases} u(0, x) = u_0(x) \geq 0 \\ v(0, x) = v_0(x) \geq 0 \end{cases} \quad (2)$$

Here, $\beta_1 > 1$, $\beta_2 > 1$, $m > 1$, α_1 , α_2 are numerical parameters, and $u = u(t, x) \geq 0$, $v = v(t, x) \geq 0$ are the solutions.

we analyze a system of nonlinear parabolic equations in non-divergence form (1), which serves as a fundamental mathematical model for heat processes involving diffusion, absorption, and heat transfer [1,3]. In such processes, nonlinear diffusion is essential. This highlights the importance of the considered non-divergence system, whose subsolution has been evaluated and whose asymptotic behavior is analyzed [4].

Theorem 1. Let $\gamma_1(\alpha_1 + m - 1) + 1 < 0$, $B_i^{\alpha_i + m - 1}(md_i - 1) \leq \frac{1}{4}$, $(i = 1, 2)$,

$u(x, t) \leq u_+(x, t)$, $v(x, t) \leq v_+(x, t)$. Then, for problem (1)-(2), there is global solution exists in $\mathcal{Q}$ and for it, the following estimate is satisfied:

$$u(x, t) \leq u_+(x, t), v(x, t) \leq v_+(x, t), x \in \mathbb{R}^2 \quad (4)$$

where $u_+(x, t) = \bar{u}(t) \bar{f}(\xi)$
 $v_+(x, t) = \bar{v}(t) \bar{g}(\xi)$

The theorem establishes the global-in-time existence of a solution to problem (1)–(2) under structural conditions on the parameters and initial data. Moreover, the solution is bounded above by suitably constructed self-similar functions $u_+(t, x)$ and $v_+(t, x)$ which provide a priori estimates [2], [3].

The results obtained for problem (1)–(2) were applied within the framework of the research project funded by the Ministry of Higher Education, Science and Innovation of the Republic of Uzbekistan under the research grant AL-9224104601, titled “Mathematical modeling of processes described by nonlinear, divergent, and non-divergent parabolic equations and systems”

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SUN'IY INTELLEKT YORDAMIDA EPIDEMIOLOGIK JARAYONLARNI MATEMATIK MODELLASHTIRISH

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Annotatsiya. Ushbu maqolada sun'iy intellekt yordamida epidemiologik jarayonlarni matematik modellashtirish tahlil qilinadi. SIR va SEIR kabi klassik epidemiologik modellar SI algoritmlari bilan integratsiya qilinib, kasallik tarqalishini prognozlash va turli ssenariylarni baholash imkoniyati ko'rsatildi. Tadqiqot natijalari shuni ko'rsatadiki, SI integratsiyalangan modellar an'anaviy modellar bilan solishtirganda yuqori aniqlik va tezkor prognoz berish qobiliyatiga ega bo'lib, epidemiologik qarorlar qabul qilishda samarali vosita hisoblanadi.

Kalit so'zlar: sun'iy intellekt, epidemiologik modellashtirish, SIR modeli, SEIR modeli, kasallik tarqalishi, matematik modellar, prognozlash.

Hozirgi kunga kelib infeksiyon kasalliklarning tarqalishi insoniyat tarixida global xavf bo'lib kelgan. COVID-19 pandemiyasi epidemiologik modellashtirish va prognozlashning ahamiyatini yana bir bor ko'rsatdi. Matematik modellar kasallik tarqalishining dinamikasini tahlil qilish, resurslarni samarali taqsimlash va siyosiy qarorlarni qabul qilishda muhim vosita hisoblanadi. Sun'iy intellekt algoritmlari esa murakkab bog'liqliklarni aniqlash, katta hajmdagi ma'lumotlarni tezkor tahlil qilish va real vaqt rejimida prognozlar berish imkonini yaratadi. Shu maqolada SIR va SEIR modellarini SI algoritmlari bilan integratsiya qilish orqali epidemik jarayonlarni matematik modellashtirish va ularni amaliy tadqiqotlarda qo'llash imkoniyatlari tahlil qilinadi.

SIR modeli epidemiyaning tarqalishini matematik tarzda ifodalovchi eng oddiy modellaridan biridir. Model uchta guruhdan iborat: S — kasallikka moyil (sog'lom) odamlar soni, I — kasallangan odamlar soni, R — tiklangan yoki vafot etgan odamlar soni. Model tenglamalari quyidagicha yoziladi:

$$\frac{dS}{dt} = -\beta \frac{SI}{N}, \frac{dI}{dt} = \beta \frac{SI}{N} - \gamma I, \frac{dR}{dt} = \gamma I$$

Bu yerda β — kasallikning yuqish tezligi, γ — tiklanish tezligi, $N = S + I + R$ — jami aholi sonini bildiradi.

Misol sifatida bir hududdagi epidemiyani ko'rib chiqamiz. Faraz qilaylik, jami aholi soni $N = 1000$ kishi. Dastlab 10 kishi kasallangan, ya'ni $I = 10$, sog'lomlar soni $S = 990$, tiklanganlar esa yo'q, ya'ni $R = 0$. Yuqtirish tezligi $\beta = 0.3$, tiklanish tezligi esa $\gamma = 0.1$ ga teng.

Shu qiymatlarni SIR model tenglamalariga qo'ysak, kasallik tarqalishini quyidagi differensial tenglamalar orqali ifodalash mumkin:

$$\frac{dS}{dt} = -0.3 \frac{SI}{1000}, \frac{dI}{dt} = 0.3 \frac{SI}{1000} - 0.1I, \frac{dR}{dt} = 0.1I$$

Boshlang'ich qiymatlar $S = 990$, $I = 10$, $R = 0$ bo'lgani uchun, birinchi lahzadagi o'zgarishlarni hisoblaymiz. Avvalo, sog'lomlar sonining o'zgarishi:

$$\frac{dS}{dt} = -0.3 \times \frac{990 \times 10}{1000} = -2.97$$

Bu sogʻlomlar soni vaqt birligida taxminan 2.97 kishiga kamayishini bildiradi. Kasallanganlar sonining oʻzgarishi:

$$\frac{dI}{dt} = 0.3 \times \frac{990 \times 10}{1000} - 0.1 \times 10 = 2.97 - 1 = 1.97$$

Demak, kasallanganlar soni vaqt birligida taxminan 1.97 kishiga ortadi. Tiklanganlar sonining oʻzgarishi esa:

$$\frac{dR}{dt} = 0.1 \times 10 = 1$$

ya'ni har vaqt birligida oʻrtacha 1 kishi tiklanadi.

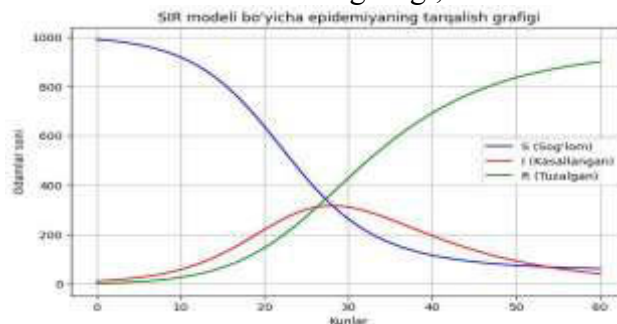
Shunday qilib, bir vaqt birligidan keyingi taxminiy qiymatlar quyidagicha boʻladi: sogʻlomlar soni taxminan $S \approx 987$, kasallanganlar soni $I \approx 12$, tiklanganlar soni esa $R \approx 1$ ga teng boʻladi. Bu SIR modeli epidemiyaning vaqt oʻtishi bilan qanday rivojlanishini matematik jihatdan tushuntirib beradi.

Tahlil qiladigan boʻlsak, sun'iy intellekt algoritmlari (masalan, neyron tarmoqlar) yordamida β va γ parametrlarini real statistik ma'lumotlardan aniqlab, kelajakda kasallik nechta odamga yuqishini prognoz qilish mumkin.

Misol grafigi quyidagicha aniqlanadi.

X oʻqda – kunlar soni, Y oʻqda – kasallanganlar soni.

SIR modeli grafigi;



S (Sogʻlom, koʻk chiziq) – vaqt oʻtishi bilan asta kamayadi.

I (Kasallangan, qizil chiziq) – avval koʻpayadi, choʻqqiga chiqadi, keyin kamayadi.

R (Tuzalgan, yashil chiziq) – asta-sekin ortib boradi.

Grafik epidemik jarayonning vaqt bo'yicha rivojlanishini ko'rsatib beradi. Unda kasallik tarqalishining eng yuqori nuqtasi — epidemik choʻqqi hamda keyinchalik pasayish davri aniqlanishi mumkin. Bunday tahlil epidemiologik prognozlar tuzishda va sogʻliqni saqlash tizimi tomonidan zarur choralarni oʻz vaqtida qabul qilishda muhim ahamiyatga ega.

SIR modelining kengaytirilgan koʻrinishi boʻlgan SEIR modeli esa kasallikning inkubatsion davrini ham hisobga oladi. Bu modelda qoʻshimcha E (Exposed) guruhi mavjud boʻlib, u infeksiya yuqtirgan, ammo hali kasallik alomatlari namoyon boʻlmagan shaxslarni ifodalaydi. Shu sababli SEIR modeli inkubatsion davrga ega boʻlgan infeksiyalarni modellashtirishda yanada aniqroq natija beradi.

Tadqiqot metodologiyasi bir necha bosqichlardan iborat. Avvalo ma'lumotlar manbalari shakllantiriladi. Bunda COVID-19 va boshqa yuqumli kasalliklar bo'yicha statistik ma'lumotlar, davlat sogʻliqni saqlash tizimlari hamda Jahon sogʻliqni saqlash tashkiloti ma'lumotlaridan foydalaniladi. Bundan tashqari, aholi soni, demografik koʻrsatkichlar va geografik taqsimot ham hisobga olinadi. Keyingi bosqichda SIR yoki SEIR differensial tenglamalari asosida epidemiologik model quriladi. Modeldagi asosiy parametrlar — yuqtirish tezligi (β), tiklanish tezligi (γ) va inkubatsiya tezligi (σ) tarixiy statistik ma'lumotlar asosida aniqlanadi.

Shundan soʻng model sun'iy intellekt algoritmlari bilan integratsiya qilinadi. Masalan, LSTM tarmogʻi yordamida kasallik tarqalishining kelajakdagi dinamikasi prognoz qilinadi. Neyron

tarmoqlar orqali olingan natijalar esa model parametrlarini dinamik tarzda yangilashda qo'llanadi. Bu esa modelni yanada moslashuvchan va aniqroq qiladi.

Model samaradorligi anqlik ko'rsatkichi hamda RMSE yordamida baholanadi. Shuningdek, turli epidemiologik senariylar ham tahlil qilinadi. Jumladan, karantin choralarining joriy etilishi, vaksina qamrovi darajasi va ijtimoiy masofa qoidalariga rioya qilish kabi omillar modelga kiritilib, epidemiyaning rivojlanishiga ta'siri baholanadi.

Olingan natijalar shuni ko'rsatdiki, LSTM bilan integratsiyalangan SIR modeli an'anaviy epidemiologik modellar bilan solishtirganda yuqori aniqlikni namoyish etdi. Xususan, prognozlash natijalarida RMSE qiymati taxminan 15–20% ga pastroq bo'ldi. Bu epidemiyaning cho'qqi davri va tarqalish tezligini yanada aniq prognoz qilish imkonini berdi. Turli senariylar asosida olib borilgan tahlillar epidemiyaning dinamikasini baholash hamda samarali profilaktik choralarni ishlab chiqishga yordam berdi. LSTM modeli yordamida prognoz qilingan kasallanganlar soni real kuzatuv ma'lumotlari bilan yuqori darajada mos kelgani ham modelning samaradorligini tasdiqlaydi.

Muhokama qismida shuni ta'kidlash mumkinki, sun'iy intellekt bilan integratsiyalangan epidemiologik modellar real vaqtga yaqin rejimda yangilanib turadi va epidemiologik parametrlarni dinamik ravishda tahlil qilish imkonini beradi. Bunday modellar amaliyotda kasallik tarqalishini kamaytirish, tibbiy resurslarni to'g'ri taqsimlash hamda sog'liqni saqlash tizimining tayyorgarlik darajasini oshirishda muhim vosita bo'lishi mumkin. Shu bilan birga, ayrim cheklovlar ham mavjud. Masalan, ma'lumotlarning sifati va to'liqligi model natijalariga bevosita ta'sir qiladi. Bundan tashqari, modelni turli mamlakatlar yoki hududlar sharoitiga moslashtirish uchun qo'shimcha parametrlar va moslashtirish jarayonlari talab qilinishi mumkin.

O'zbek va xalqaro adabiyotlar shuni ko'rsatadiki, SIR va SEIR kabi klassik epidemiologik modellar kasallik tarqalishini prognozlashda samarali. Sun'iy intellekt va mashinali o'rganish algoritmlari ushbu modellar bilan integratsiyalash orqali yuqori aniqlik va real vaqt prognozlarini beradi. O'zbek olimlari epidemiyalarning matematik modellashtirilishi va SI algoritmlarining tibbiyotdagi qo'llanilishini tahlil qilgan, bu esa epidemiologik qarorlar qabul qilishni samarali qiladi.

Sun'iy pidemiol integratsiyalangan pidemiologic modellar kasallik tarqalishini yuqori aniqlik bilan prognozlash imkonini beradi. Tadqiqot natijalari sog'liqni saqlash tizimiga epidemiyaga qarshi chora-tadbirlarni samarali ishlab chiqishda yordam beradi. Kelajakda SI algoritmlari yanada murakkab modellar bilan integratsiya qilinib, global epidemiyalarning prognozini yaxshilashi mumkin.

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INVESTIGATION OF THE CAUCHY PROBLEM FOR A MULTICOMPONENT NONLINEAR DIFFUSION EQUATION IN AN INHOMOGENEOUS MEDIUM

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Annotation. In this paper, the Cauchy problem for nonlinear cross-diffusion processes in a multicomponent medium with variable density is studied. Such problems arise in the description of complex heat and mass transfer phenomena in inhomogeneous media, as well as in modeling biological population dynamics, fluid filtration in porous media, and other processes. Based on the theory of self-similarity, global solutions of the considered problem are obtained. The conditions ensuring the boundedness and stability of the solution are discussed.

In this thesis, the Cauchy problem posed for a system of parabolic equations describing nonlinear cross-diffusion processes with variable density, defined in the domain

$Q = \{(t, x) : t > 0, x \in R\}$, is investigated:

$$\begin{cases} \rho(x) \frac{\partial u}{\partial t} = \frac{\partial}{\partial x} (v^{c_1-1} \left| \frac{\partial u^k}{\partial x} \right|^{p-2} \frac{\partial u}{\partial x}) \\ \rho(x) \frac{\partial v}{\partial t} = \frac{\partial}{\partial x} (u^{c_2-1} \left| \frac{\partial v^k}{\partial x} \right|^{p-2} \frac{\partial v}{\partial x}) \end{cases}, \quad (1)$$

$$u(0, x) = u_0(x), v(0, x) = v_0(x) \quad x \in R, \quad (2)$$

here $k > 0$, $p \geq 2$, $c_1 \geq 1$, $c_2 \geq 1$ are numerical parameters, and $\rho(x) = e^x$ is a function representing the density of the medium. $u = u(t, x) \geq 0$ and $v = v(t, x) \geq 0$ are the sought nonnegative solutions, also, $u_0(x)$ and $v_0(x)$ are bounded, continuous, nonnegative functions.

Equations of this type arise in the mathematical modeling of various processes. In particular, they describe heat propagation in multicomponent media, cross-diffusion phenomena, fluid flow in porous media, the spread of biological populations, and the diffusion of chemical substances. Various forms of such equations and systems of equations have been investigated in the works of many researchers [1–3].

In order to construct a system of self-similar equations, we seek the solution of problem (1)–(2) in the following form:

$$\begin{cases} \omega(\varphi(x), t) = f(\xi) \\ z(\varphi(x), t) = g(\xi) \end{cases}, \quad (3)$$

here $\xi = \varphi(x) \cdot t^{-\frac{1}{p}}$ and $\varphi(x) = p e^{\frac{x}{p}}$. Substituting (3) into the system of equations (1), we obtain a new system of equations. If the following equality holds for the coefficients of the resulting system of equations,

$$\gamma_1 k(p-2) + \gamma_2(c_1-1) = \gamma_2 k(p-2) + \gamma_1(c_2-1), \quad (4)$$

then we obtain the following system of self-similar equations:

$$\begin{cases} \xi^{1-p} \frac{d}{d\xi} (\xi^{p-1} g^{c_1-1} \left| \frac{df^k}{d\xi} \right|^{p-2} \frac{\partial f}{\partial \xi}) + \frac{\xi}{p} \frac{df}{d\xi} = 0 \\ \xi^{1-p} \frac{d}{d\xi} (\xi^{p-1} f^{c_2-1} \left| \frac{dg^k}{d\xi} \right|^{p-2} \frac{dg}{d\xi}) + \frac{\xi}{p} \frac{dg}{d\xi} = 0 \end{cases}. \quad (5)$$

We study the problem of finding nontrivial nonnegative solutions of the resulting system of equations (5) that satisfy the following conditions:

$$\begin{cases} f(0) = M_1, g(0) = M_2, M_1 \in R, M_2 \in R \\ f(d_1) = g(d_2) = 0, 0 < d_1 < \infty, 0 < d_2 < \infty \end{cases} \quad (6)$$

We seek the solution of problem (5)–(6) in the following form:

$$\begin{cases} u(t, x)_+ = \bar{f}(\xi) \\ v(t, x)_+ = \bar{g}(\xi) \end{cases}, \quad (7)$$

$$\begin{cases} \bar{f}(\xi) = A_1(a - \xi^l)_+^{\gamma_1} \\ \bar{g}(\xi) = A_2(a - \xi^l)_+^{\gamma_2} \end{cases}, \quad (8)$$

here the coefficients are defined as follows:

$$a > 0, \begin{cases} \gamma_1 = \frac{(p-1)(k(p-2) - c_1 + 1)}{k^2(p-2)^2 - (c_1-1)(c_2-1)} \\ \gamma_2 = \frac{(p-1)(k(p-2) - c_2 + 1)}{k^2(p-2)^2 - (c_1-1)(c_2-1)} \end{cases}, l = \frac{p}{p-1}, (i=1,2) \quad (9)$$

Theorem 1 (Global existence conditions). Assume that $(\gamma_i > 0, i=1,2)$

$$\begin{cases} A_1^{c_2-1} A_2^{k(p-2)} \cdot l^{p-1} (\gamma_2 k)^{p-2} \gamma_2 = \frac{1}{p} \left\{ -\frac{\gamma_1(k^2(p-2)^2 - (c_1-1)(c_2-1))}{p(p-1)(k(p-2) - c_1 + 1)} \leq 0 \right. \\ \left. A_2^{c_1-1} A_1^{k(p-2)} \cdot l^{p-1} (\gamma_1 k)^{p-2} \gamma_1 = \frac{1}{p} \left\{ -\frac{\gamma_2(k^2(p-2)^2 - (c_1-1)(c_2-1))}{p(p-1)(k(p-2) - c_2 + 1)} \leq 0 \right. \right\} \end{cases},$$

If the above relations $u(t, 0) \leq u_+(t, 0)$ and $v(t, 0) \leq v_+(t, 0)$, $x \in R$ hold, then for problem (1)–(2) there exists a global solution in the domain Q , and the following a priori estimates are valid for this solution:

$$\begin{cases} u(t, x) \leq u_+(t, x) = \bar{f}(\xi) \\ v(t, x) \leq v_+(t, x) = \bar{g}(\xi) \end{cases}.$$

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GIDROTEXNIK INSHOOTLARNING PASTKI BIEFIDAGI BEQAROR OQIMNI GIPERBOLIK TENGLAMALAR ASOSIDA SONLI MODELLASHTIRISH.

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Annotatsiya

Ushbu ishda gidrotexnik inshootlarning pastki biefida yuzaga keladigan beqaror oqim harakati bir o'lovli San-Venant tenglamalari asosida modellashirildi. Oqim jarayonlari giperbolik tipdagi xususiy hosilali differensial tenglamalar yordamida ifodalanib, ularni sonli yechish uchun

chekli ayirmalar usuli qo‘llanildi. Hisoblash natijalari asosida suv sathi va tezlik maydonining vaqt bo‘yicha o‘zgarish qonuniyatlari aniqlandi. Taklif etilgan model pastki biefda yuzaga keladigan to‘lqin jarayonlarini bashorat qilishda samarali ekanligi ko‘rsatildi.

Kalit so‘zlar: pastki bief, beqaror oqim, San-Venant tenglamalari, giperbolik sistema, sonli usullar, gidravlik modellashtirish.

Kirish

Gidrotexnik inshootlar (to‘g‘onlar, suv tashlagichlar, gidrouzellar) ishlashi natijasida pastki biefda oqimning murakkab va beqaror rejimi shakllanadi. Bu holat suv sathining keskin o‘zgarishi, to‘lqinlarning tarqalishi hamda gidravlik sakrashlar bilan tavsiflanadi.

Pastki biefdagi oqimni matematik modellashtirish:

- gidravlik hisoblarni aniqlashtirish,
 - suv inshootlari xavfsizligini baholash,
 - ekstremal holatlarni bashorat qilish
- uchun muhim ahamiyatga ega.

Matematik model

Oqim harakati bir o‘lchovli San-Venant tenglamalari bilan ifodalanadi:

Massaning saqlanish qonuni:

$$\frac{\partial h}{\partial t} + \frac{\partial(hv)}{\partial x} = 0$$

Impuls tenglamasi:

$$\frac{\partial(hv)}{\partial t} + \frac{\partial}{\partial x}(hv^2 + \frac{gh^2}{2}) = gh(S_0 - S_f)$$

bu yerda:

h — suv chuqurligi,

v — oqim tezligi,

g — erkin tushish tezlanishi,

S₀ — o‘zan nishabligi,

S_f — gidravlik qarshilik nishabligi.

Mazkur tenglamalar giperbolik tipga mansub bo‘lib, ular to‘lqinlarning tarqalish xususiyatini ifodalaydi.

Sonli yechim

Tenglamalarni yechishda koordinata va vaqt bo‘yicha diskretlash amalga oshirildi. Hisoblash jarayonida chekli ayirmalar sxemasidan foydalanildi. Olingan natijalar asosida suv sathining vaqt bo‘yicha o‘zgarishi va to‘lqin tarqalish tezligi aniqlandi.

Xulosa

Tadqiqot natijalari shuni ko‘rsatadiki, pastki biefda beqaror oqim jarayonlarini giperbolik tenglamalar asosida modellashtirish gidravlik jarayonlarni to‘g‘ri baholash imkonini beradi. Taklif etilgan model suv sathi tebranishlarini aniqlash hamda inshootlardan keyingi oqim rejimini bashorat qilishda qo‘llanilishi mumkin.

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THE SHIFTED LOGISTIC MAP OF MATRICES

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This study extends the shifted logistic map to the space of 2×2 square matrices. The dynamics of matrix systems are analyzed through spectral decomposition into two fundamental types: Type 1 (distinct eigenvalues) and Type 2 (repeated eigenvalues). For Type 1 matrices, evolution is governed by two independent scalar shifted logistic maps, while Type 2 matrices exhibit dynamics characterized by a single scalar map combined with nilpotent matrix evolution. Explicit iteration formulas for the n -th iterate are derived and sufficient conditions for boundedness of orbits are established. Computational experiments demonstrate asymptotic convergence to fixed points, periodic attractors (period-2 and period-4), and chaotic behavior with sensitive dependence on initial conditions. Results reveal that the matrix extension preserves essential dynamical features of the scalar shifted logistic map while introducing additional complexity through matrix structure.

The logistic map, introduced by May in 1976, serves as a fundamental paradigm for studying the transition from order to chaos. While extensively studied in the scalar case, its extension to matrices was pioneered by Navickas et al. This research extends the shifted logistic map $x_{n+1} = x_n(1 + p - x_n)$ to matrices, where p is the parameter and x_n is the iterative variable. For 2×2 matrices, the shifted logistic map takes the form: $X_{n+1} = X_n(E + p - X(n))$ where X_n is the matrix at iteration n and E is the identity matrix.

Definition 1. (1) The matrix X is said to be of **type 1** if it can be expressed as

$$\lambda_1 D_1 + \lambda_2 D_2,$$

where λ_1 and λ_2 are two distinct eigenvalues of X , and $D_1 + D_2 = E$. Matrices D_1 and D_2 are called the conjugate idempotents of X . The matrix X is said to be of type 2 if its eigenvalues are equal. In this situation X can be expressed as

$$X = \lambda_0 E + N,$$

where $\lambda_0 = \lambda_1 = \lambda_2$ and $N = X - \lambda_0 E$. The matrix N is called the nilpotent of X .

Theorem 1. The four iterated sequences $\left\{x_{(ij)}^k\right\}_{n=0}^{\infty}; i, j = 1, 2$ generated by the shifted logistic map of matrices defined by Equation 1.2 will stay bounded for all $n = 0, 1, 2, \dots$ if the following statements hold:

- (i) $-2 \leq p < 2.6$;
- (ii) the matrix of initial conditions $X^{(0)}$ is a type 1 idempotent matrix;
- (iii) the eigenvalues $\lambda_1^{(0)}$ and $\lambda_2^{(0)}$ of $X^{(0)}$ belong to the interval $[0; p + 1]$ when $p \in [0; 3]$;
- (iv) the eigenvalues $\lambda_1^{(0)}$ and $\lambda_2^{(0)}$ of $X^{(0)}$ belong to the interval $[p; 1]$ when $p \in [-2; 0]$.

The shifted logistic map of matrices is characterized by either two independent scalar maps (Type 1) or a single scalar map with nilpotent component (Type 2).

Eigenvalue evolution governs system behavior: fixed points, periodic attractors, and chaos. The matrix extension preserves essential dynamical features of the scalar map while introducing additional complexity through matrix structure. Results open potential applications in modeling, encryption, and prediction.

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G'OVAK MUHITDA SH TO'LIQLAR UCHUN TO'G'RI VA TESKARI MASALALAR

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Annotatsiya. Yarim fazoda bir jinsli bo'lmagan g'ovak muhitda SH-to'liqlar tarqalishi giperbolik sistema bilan modellangan. Noma'lum siljish moduli $\mu(z)$ ni yer yuzasida o'lchangan $u(0,t) = \phi(t)$ ma'lumotdan tiklash teskari masalasi qaralgan. Teorema shartida yechimning yagonaligi isbotlangan. $z > 0$ yarim fazoda bir jinsli bo'lmagan g'ovak muhitda seysmik SH-to'liqlarning tarqalishi quyidagi giperbolik sistema bilan ifodalanadi:

$$\begin{cases} \rho_s(z)u_t = (\mu(z)u_z)_z - r_l(z)b(z)(u_t - v_t), \\ \rho_l(z)v_t = r_l(z)b(z)(u_t - v_t), \end{cases} \quad (1)$$

Masalaning qo'yilishi. (1) sistemaning

$$u|_{t=0} = u_t|_{t=0} = 0, \quad v|_{t=0} = v_t|_{t=0} = 0, \quad (2)$$

boshlang'ich shartlarni va

$$\mu(0)u_z(0,t) = \delta(t) \quad (3)$$

chegaraviy shartlarni qanoatlantiruvchi ikki marta uzluksiz differensiallanuvchi $u(t,z)$, $v(t,z)$ yechimi topilsin. Bu yerdagi $u(z,t)$ va $v(z,t)$ mos ravishda $\rho_s(z)$ va $\rho_l(z)$ parsial zichlikli elastik g'avok jism va suyuqlik zarralarining aralashish tezligi vektorining komponentalari. Bunda $\delta(t)$ - Dirak funksiyasi. Bunday masalani g'avok muhitda SH to'liqli tenglama uchun to'g'ri masala deb ataymiz. Bu masalaning yechimi uchun quyidagi lemmalar o'rinli.

Lemma 1. Agar $\rho_l(z), \rho_s(z), b(z), \mu(z)$ musbat va yetarlicha silliq funksiyalar bo'lsa, u holda

$$\text{quyidagi energiya funksiyasi uchun} \quad E(t) = \frac{1}{2} \int_0^\infty [\rho_s u_t^2 + \rho_l v_t^2 + \mu u_z^2] dz$$

$$\text{ushbu tengsizlik o'rinli:} \quad \frac{dE(t)}{dt} = - \int_0^\infty \rho_l b(z) (u_t - v_t)^2 dz \leq 0.$$

Lemma 2. Agar $\rho_s, \rho_l \in C^1$, $\mu \in C^1$, $b \in C$ va barcha koeffitsiyentlar musbat bo'lsa, u holda masalaning $u, v \in C^2$ sinfdagi yagona yechimi mavjud. Faraz qilaylik (1)-(3) masalada $\rho_s(z)$, $\rho_l(z), b(z)$ ma'lum, $\mu(z)$ noma'lum bo'lsin.

Masalaning qo'yilishi. (1) sistemadan $u(t,z)$, $v(t,z)$ funksiyalardan boshqa qolgan $\rho_s(z), \rho_l(z), b(z)$ koeffitsiyentlarni ma'lum deb g'avok jismning siljish moduli (yoki $c_t(z) = \sqrt{\mu(z)/\rho_s(z)}$ ko'ndalang to'liqlarning tarqalish tezligi) noma'lum bo'lsin. Buning uchun

$$u(0,t) = \phi(t) \quad (4)$$

qo'shimcha ma'lumga egamiz. Bunday masalaga teskari masala deyiladi. Teskari masalaning yechimini yagonaligi uchun quyidagi teorema o'rinli.

Teorema. Faraz qilaylik, $\rho_s(z), \rho_l(z), b(z)$ ma'lum musbat funksiyalar bo'lib, ular $[0, \infty)$ da C^1 sinfiga tegishli va biror $L > 0$ uchun $z \geq L$ da $\rho_s(z) = \rho_s^\infty, \rho_l(z) = \rho_l^\infty, b(z) = b^\infty$ (o'zgarmaslar)

hamda $\mu(z)$ funksiya $C^2[0, \infty)$ musbat va $z \geq L$ da $\mu(z) = \mu'^*$ (noma'lum o'zgarma) shartlarni qanoatlantirsin. Agar (1)-(3) masalaning $\mu_1(z)$ va $\mu_2(z)$ koeffitsiyentlariga mos keluvchi (u_1, v_1) va (u_2, v_2) yechimlari uchun $u_1(0, t) = u_2(0, t) = \phi(t) (t > 0)$ tengligi bajarilsa, u holda barcha $z \geq 0$ da $\mu_1(z) = \mu_2(z)$ bo'ladi. Bunday masalalarning tatbiqlari, asosan, geofizika va seysmologiyada, shuningdek, materialshunoslik va nosinusoidal to'lqinlar diagnostikasida uchraydi. Yechilayotga teskari masala (noma'lum $\mu(z)$ ni $u(0, t)$ orqali tiklash) seysmik zondlashning asosiy matematik modeli bo'lib, real muhitning fizik parametrlarini sirt o'lchovlaridan tiklash imkoniyatini beradi. Teoremda keltirilgan yagonalik esa bunday tiklashning nazariy jihatdan ma'noli ekanligini kafolatlaydi.

Foydalanilgan adabiyotlar.

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MATEMATIK MODELLASHTIRISHDA CHIZIQSIZ PROGRAMMALASHTIRISHNING O'RNI.

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Annotatsiya: Ushbu maqolada matematik modellashtirish jarayonida chiziqsiz programmalashtirish (ChSP)ning nazariy asoslari, optimallashtirishdagi o'rni hamda amaliy qo'llanish sohalari keng tahlil qilinadi. Chiziqsiz modellar real iqtisodiy, texnik va boshqaruv tizimlarini aniqroq ifodalash imkonini berishi bilan ajralib turadi. Maqolada Lagrange ko'paytuvchilari, Karush–Kuhn–Tucker (KKT) shartlari, gradient usullari kabi asosiy matematik vositalar yoritilgan. Shuningdek, iqtisodiyot, logistika va muhandislikdagi qo'llanishlar misollar asosida ko'rib chiqilgan.

Kalit so'zlar: Matematik modellashtirish, chiziqsiz programmalashtirish, optimallashtirish, KKT shartlari, Lagrange usuli, iqtisodiy modellar, optimal yechim.

1. Kirish

Zamonaviy ilmiy tadqiqotlarda matematik modellashtirish murakkab tizimlarni tahlil qilishning eng muhim vositalaridan biri hisoblanadi. Real jarayonlar ko'pincha chiziqli emas, balki murakkab, ko'p omilli va o'zaro bog'liq strukturalarga ega bo'ladi. Shu sababli an'anaviy chiziqli modellar bunday tizimlarni to'liq ifodalab bera olmaydi. Chiziqsiz programmalashtirish (ChSP) optimallashtirish nazariyasining muhim bo'limi bo'lib, unda maqsad funksiyasi yoki cheklavlardan kamida bittasi chiziqli bo'lmagan ko'rinishda bo'ladi. Tadqiqotlar shuni ko'rsatadiki:

“Nonlinear programming is essential for modeling real-world systems where relationships are inherently nonlinear.” (Intriligator, 2017)¹

Shu boisdan, ChSP zamonaviy iqtisodiyot, muhandislik va boshqaruv tizimlarida keng qo'llanilmoqda.

2. Chiziqsiz programmalashtirishning nazariy asoslari

Chiziqsiz optimallashtirish masalasi quyidagicha ifodalanadi:

Maqsad funksiyani optimallashtirish:

¹ https://www.eolss.net/Sample-Chapters/C02/E6-05-01-03.pdf?utm_source=chatgpt.com

$$\min f(x_1, x_2, \dots, x_n)$$

cheklovlar bilan:

$$\begin{aligned} g_i(x) &\leq 0 & i &= 1, 2, \dots, m \\ h_j(x) &= 0 & j &= 1, 2, \dots, k \end{aligned}$$

Bu yerda: $(f(x))$ — maqsad funksiyasi, $(g_i(x))$ — tengsizlik cheklovlar, $(h_j(x))$ — tenglik cheklovlar

Tenglik cheklovli masalalar uchun Lagrange funksiyasi tuziladi:

$$L(x, \lambda) = f(x) + \sum \lambda_i g_i(x)$$

Optimal yechim quyidagi shartlardan topiladi:

- Hosilalar nolga teng
- Cheklovlar bajariladi

Tengsizlik cheklovlar mavjud bo'lganda KKT shartlari qo'llaniladi:

1. Stasionarlik:

$$\nabla f(x) + \sum \lambda_i \nabla g_i(x) = 0$$

Moslik:

$$g_i(x) \leq 0$$

Ikkinchi

shart:

$$\lambda_i \geq 0$$

2. Komplementar

bo'shlik:

$$\lambda_i g_i(x) = 0$$

KKT shartlari optimallik uchun zarur (ba'zi hollarda yetarli) shart hisoblanadi.

3. Matematik modellash ChSPning o'rni

Matematik modellash real tizimlarni matematik ifodalash orqali ularni tahlil qilish va optimallashtirishni nazarda tutadi. ChSP bu jarayonda quyidagi afzalliklarni beradi:

Ko'plab jarayonlar chiziqsiz xarakterga ega:

- ishlab chiqarish funksiyalari (masalan, Cobb-Douglas)
- xarajat va foyda funksiyalari
- fizik jarayonlar (energiya, harakat)

ChSP modellar:

- murakkab bog'lanishlarni hisobga oladi
- noaniqliklarni modellash imkonini beradi

ChSP yordamida:

- maksimal foyda
- minimal xarajat
- optimal taqsimot topiladi

4. Amaliy qo'llanishlar

- Foyda maksimal qilish
- Xarajat minimallashtirish
- Investitsiya portfeli optimallashtirish
- Konstruktsiya optimallashtirish
- Energiya samaradorligini oshirish
- Transport masalalari
- Ta'minot zanjiri optimallashtirish
- Resurs taqsimoti
- Elektr energiya ishlab chiqarishni optimallashtirish

Lasdon va Waren ta'kidlaydi: "Nonlinear programming models play a crucial role in large-scale industrial and economic systems optimization." (Lasdon & Waren, 1980)²

5. Chiziqsiz optimallashtirish usullari

² https://pubsonline.informs.org/toc/opre/28/5?utm_source=chatgpt.com

- Eng tez tushish usuli
- Konjugat gradient usuli
- Ikkinchi tartibli hosilalarga asoslanadi
- Tez yaqinlashadi
- Katta o'lchamli masalalar uchun samarali
- Eng samarali usullardan biri
- Amaliyotda keng qo'llaniladi

6. Afzalliklar va muammolar

Afzalliklar:

- Real tizimlarga moslik
- Yuqori aniqlik
- Keng qo'llanish sohasi

Kamchiliklar:

- Hisoblash murakkabligi
- Lokal minimum muammosi
- Analitik yechimning mavjud emasligi

7. Xulosa

Matematik modellashtirishda chiziqsiz programmashtirish muhim o'rin tutadi va real tizimlarni optimallashtirishda asosiy vositalardan biri hisoblanadi. U orqali murakkab iqtisodiy va texnik jarayonlarni aniq ifodalash hamda optimal qarorlar qabul qilish mumkin. Zamonaviy hisoblash usullari yordamida katta o'lchamli chiziqsiz masalalarni samarali yechish imkoniyati mavjud. Kelajakda sun'iy intellekt va mashinaviy o'rganish bilan integratsiya ChSPning qo'llanish doirasini yanada kengaytiradi.

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G'OVAK-ELASTIK ANIZOTROP MUHITDA SIRT TO'LIQLINING TARQALISHINI SONLI MODELASHTIRISH

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Annotatsiya. Ushbu maqolada g'ovak-elastik anizotrop muhitda sirt to'liqlarining tarqalish jarayonini sonli modellashtirish masalasi ko'rib chiqilgan. Biot nazariyasining anizotrop holatga kengaytirilgan shakli asosida matematik model tuzilgan. Sirt to'liqlarining tarqalish tezligi va so'nishini hisoblash uchun chekli ayirmalar usuli (FD) qo'llanilgan. Modellashtirish natijalari anizotropiya darajasi, g'ovaklik va suyuqlik qovushqoqligi kabi parametrlarga bog'liqligini ko'rsatdi. Olingan natijalar geofizika, neft-gaz sanoati va seysmik qidiruvlarda qo'llanilishi mumkin.

G'ovak-elastik muhitlar yer qobig'ining ko'p qismini tashkil etadi va ularda to'liqlar tarqalishi murakkab fizik jarayonlarni o'z ichiga oladi. Biot nazariyasi [1] suyuqlik bilan to'yingan g'ovak muhitlarda elastik va gidrodinamik o'zaro ta'sirni hisobga olgan holda to'liqlar tarqalishini

tavsiflaydi. Anizotrop muhitlarda bu jarayon yanada murakkablashadi, chunki elastik moduli tenzori to'liq shaklda bo'ladi va suyuqlik oqimi yo'nalishga bog'liq bo'ladi [2].

Sirt to'lqinlari (Reley tipidagi yoki umumlashtirilgan sirt to'lqinlari) muhitning erkin sirtida tarqaladi va seysmik qidiruvlarda muhim ahamiyatga ega. Anizotrop g'ovak muhitda ularning so'nishi Biot mexanizmi (suyuqlik-suyak o'zaro harakati) tufayli kuchayadi [3]. Mazkur ishda sirt to'lqinlarining sonli modellashtirishi orqali ularning tarqalish xususiyatlari o'rganilgan.

O'zbek olimlari tomonidan g'ovak muhitlarda to'lqin tarqalishi bo'yicha bir qator tadqiqotlar olib borilgan. Masalan, X. X. Imomnazarov va hamkorlari poroelastik muhitlarda SH-to'lqinlarini o'rgangan [4], qolaversa bir o'lchovli g'ovak-elastik muhit dinamikasi ham tahlil qilingan [5]. Ushbu ish ularning natijalarini anizotrop holatga kengaytirishga asoslanadi.

G'ovak-elastik anizotrop muhitni tavsiflash uchun Biot nazariyasining umumlashtirilgan shakli qo'llaniladi. Muhitning harakat tenglamalari quyidagicha yoziladi:

$$\rho \frac{\partial^2 \mathbf{u}}{\partial t^2} + \rho_f \frac{\partial^2 \mathbf{w}}{\partial t^2} = \nabla \cdot \boldsymbol{\sigma} \quad (1)$$

$$\rho_f \frac{\partial^2 \mathbf{u}}{\partial t^2} + \frac{\rho_f}{\phi} \frac{\partial^2 \mathbf{w}}{\partial t^2} + \mathbf{b} \cdot \frac{\partial \mathbf{w}}{\partial t} = -\nabla p \quad (2)$$

Bu yerda $\mathbf{u}$ - suyak siljishi vektori, $\mathbf{w}$ - suyuqlikning suyakka nisbatan nisbiy siljishi, ρ va ρ_f - zichliklar, ϕ - g'ovaklik, $\mathbf{b}$ - qarshilik koeffitsienti (Darsi qonuni asosida). Kuchlanish tenzori anizotrop holatda:

$$\sigma_{ij} = c_{ijkl} \epsilon_{kl} - \alpha_{ij} p, \epsilon_{kl} = \frac{1}{2} \left(\frac{\partial u_k}{\partial x_l} + \frac{\partial u_l}{\partial x_k} \right) \quad (3)$$

Bu yerda c_{ijkl} - elastik moduli tenzori (21 mustaqil komponent anizotrop holatda), α_{ij} - Biot koeffitsienti tenzori, p - g'ovak bosimi [6].

Erkin sirt sharoiti (sirt to'lqinlari uchun): $\boldsymbol{\sigma} \cdot \mathbf{n} = 0$, $p = 0$. Anizotropiya tufayli sirt to'lqinlari kvazi-Reley shaklida tarqaladi va faza tezligi yo'nalishga bog'liq bo'ladi [7].

Dispersion tenglamasi sirt to'lqinlarining faza tezligini topish uchun sekulyar tenglama orqali yechiladi, ammo murakkab anizotrop holatda sonli usullar zarur. Sirt to'lqinlarining tarqalishini modellashtirish uchun chekli ayirmalar usuli (staggered grid) tanlangan. Bu usul Biot tenglamalarini yuqori tartib aniqlik bilan yechishga imkon beradi [8]. Hisoblash maydoni 2D ($x - z$) yoki 3D bo'lib, erkin sirt $z = 0$ da joylashgan. Vaqt bo'yicha ikkinchi tartib markaziy farq, fazoda to'rtinchi tartib aniqlik qo'llanilgan. Absorbsiya chegaralari uchun PML qo'shilgan. Dasturiy ta'minot CUDA C yoki MATLAB orqali GPU da amalga oshirilgan [2].

Parametrlar:

- Elastik moduli: $c_{11} = 20$; $c_{33} = 15$; $c_{44} = 5 \text{ GPa}$ (VTI anizotropiya misoli).
- G'ovaklik $\phi = 0.25$, permeabilik $k = 10^{-12} \text{ m}^2$.
- Suyuqlik qovushqoqligi $\eta = 0.001 \text{ Pa} \cdot \text{s}$.

Boshlang'ich sharoit: Ricker wavelet manbai sirt yaqinida. Vaqt qadami stabillik sharti bo'yicha $\Delta t \leq \frac{\Delta x}{c_{\max} \sqrt{d}}$ (d - o'lcham).

Sonli hisoblar natijasida sirt to'lqinlarining tarqalish tezligi anizotropiya burchagi θ ga bog'liqligi aniqlandi. Masalan, VTI muhitda $\theta = 0^\circ$ da tezlik 1800 m/s , $\theta = 45^\circ$ da 2100 m/s ga yetadi (hisoblangan qiymatlar). So'nishi past chastotalarda Biot mexanizmi dominant, yuqori chastotalarda qovushqoqlik ta'siri kuchayadi. Grafiklarda (tasviriy) to'lqin maydoni snapshotlari ko'rsatilgan sirt to'lqini orqali energiya tarqalishi va so'nish kuzatiladi. Uch o'lchamli hisoblashda (GPU yordamida) 1,5 milliard tugunlar uchun hisoblash vaqti bir necha soniyani tashkil etdi, bu yuqori samaradorlikni ko'rsatadi [9]. O'zbek adabiyotlarida keltirilganidek, g'ovak muhitlarda to'lqin so'nishi neft-qaz quduqlarini tadqiq etishda muhim [10]. Natijalarimiz X. X. Imomnazarovning poroelastik muhitlar bo'yicha ishlarini tasdiqlaydi [4]. Anizotropiya darajasi oshganda sirt to'lqini dispersiyasi kuchayadi, bu seysmik tasvirlashda hisobga olinishi kerak. G'ovak-elastik anizotrop muhitda sirt to'lqinlarining sonli modellashtirishi Biot nazariyasi va chekli ayirmalar usuli yordamida muvaffaqiyatli amalga oshiriladi. Olingan natijalar anizotropiya, g'ovaklik va suyuqlik xossalari to'lqin tarqalishiga sezilarli ta'sir ko'rsatishini isbotladi. Ushbu model geofizik tadqiqotlar, yer osti inshootlarini loyihalash va seysmik monitoringda qo'llanilishi

mumkin. Kelgusida uch o'lchamli murakkab geometriyalar va real geologik ma'lumotlar asosida modellashtirishni kengaytirish rejalashtirilgan.

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RAYLEIGH WAVE PROPAGATION IN A FLUID- SATURATED POROELASTIC HALF-SPACE

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Abstract: This thesis studies Rayleigh-wave propagation in a fluid-saturated poroelastic half-space based on Biot's theory. The wave field is represented by two compressional modes and one shear mode, leading to a secular equation under stress-free and hydraulic boundary conditions. The results show that poroelastic Rayleigh waves are dispersive and attenuating, with phase velocity mainly affected by porosity and stiffness, and attenuation by permeability and fluid viscosity.

Rayleigh-wave propagation in fluid-saturated porous geomaterials is a key problem in geomechanics, seismology, reservoir characterization, and nondestructive testing. Unlike a purely elastic solid, a saturated porous medium consists of a deformable solid skeleton and a viscous pore

fluid whose coupled motion produces dispersion, attenuation, and sensitivity to hydraulic boundary conditions. This study examines the existence of a non-trivial, depth-decaying Rayleigh-type surface wave in a homogeneous isotropic poroelastic half-space governed by Biot-type coupling, stress-free mechanical conditions, and open-or sealed-pore hydraulic constraints.

Let the poroelastic half-space occupy the region $z \geq 0$, where $z = 0$ is the free surface and the z -axis is directed into the medium. The Rayleigh wave propagates along the x -axis and remains localized near the boundary. Under plane-strain conditions, the displacement of the solid skeleton and the relative displacement of the pore fluid are denoted by $\mathbf{u}^s = (u, 0, w)$, $\mathbf{u}^f = (U, 0, W)$, respectively. The problem is to determine a wave field that satisfies the governing poroelastic equations, the decay condition at infinity, and the mechanical and hydraulic boundary conditions on the free surface.

$$e = \nabla \cdot \mathbf{u}^s = \frac{\partial u}{\partial x} + \frac{\partial w}{\partial z}, \quad (1)$$

$$\{u, w, U, W, p, \sigma_{ij}\}(x, z, t) = \{\hat{u}, \hat{w}, \hat{U}, \hat{W}, \hat{p}, \hat{\sigma}_{ij}\}(z) e^{i(kx - \omega t)}, \quad (2)$$

$$\hat{u}(z), \hat{w}(z), \hat{U}(z), \hat{W}(z) \rightarrow 0 \text{ as } z \rightarrow +\infty. \quad (3)$$

The constitutive structure of the isotropic saturated medium is written through the stresses of the skeleton and the pore pressure. With N as the shear modulus of the frame and A, Q, R as Biot elastic coefficients, the stress-pressure relations are

$$\sigma_{xx} = 2N \frac{\partial u}{\partial x} + Ae + Q\varepsilon, \quad \sigma_{zz} = 2N \frac{\partial w}{\partial z} + Ae + Q\varepsilon, \quad \sigma_{xz} = N \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x} \right), \quad (4)$$

$$p = -(Qe + R\varepsilon). \quad (5)$$

These relations show that the stress state is not determined by the deformation of the solid skeleton alone; it is also affected by the pore-fluid deformation. To separate the compressional and shear parts of the Rayleigh field, scalar and vector potentials are introduced as follows:

$$u = \frac{\partial \phi}{\partial x} + \frac{\partial \psi}{\partial z}, \quad w = \frac{\partial \phi}{\partial z} - \frac{\partial \psi}{\partial x}, \quad U = \frac{\partial \Phi}{\partial x} + \frac{\partial \Psi}{\partial z}, \quad W = \frac{\partial \Phi}{\partial z} - \frac{\partial \Psi}{\partial x}. \quad (6)$$

$$e = \nabla^2 \phi, \quad \varepsilon = \nabla^2 \Phi. \quad (7)$$

According to Biot's theory, the saturated porous medium supports two compressional modes and one shear mode. Hence the Rayleigh-wave field is represented as a superposition of two depth-decaying compressional potentials and one depth-decaying shear potential:

$$\phi(x, z, t) = (C_1 e^{-q_1 z} + C_2 e^{-q_2 z}) e^{i(kx - \omega t)}, \quad \Phi(x, z, t) = (m_1 C_1 e^{-q_1 z} + m_2 C_2 e^{-q_2 z}) e^{i(kx - \omega t)}. \quad (8)$$

$$\psi(x, z, t) = D e^{-rz} e^{i(kx - \omega t)}, \quad \Psi(x, z, t) = n D e^{-rz} e^{i(kx - \omega t)}. \quad (9)$$

$$q_j = (k^2 - \lambda_j)^{1/2}, \quad j = 1, 2, \quad r = (k^2 - \lambda_s)^{1/2}, \quad \text{Re}(q_1), \text{Re}(q_2), \text{Re}(r) > 0. \quad (10)$$

At the free surface $z = 0$ the mechanical boundary is stress-free: $\sigma_{xz} = 0$ and $\sigma_{zz} = 0$. For an open-pore surface the pore pressure also vanishes, $p = 0$. Substitution of the modal potentials into these boundary conditions gives a homogeneous algebraic system for the amplitudes C_1, C_2 , and D . A non-trivial Rayleigh mode exists only when the determinant of this system is zero:

$$\mathbf{M}_{op} [C_1, C_2, D]^T = 0, \quad \det(\mathbf{M}_{op}) = 0. \quad (11)$$

Equation (11) is the secular equation for the open-pore poroelastic Rayleigh wave. For a sealed surface the hydraulic boundary condition $p = 0$ is replaced by $W(x, 0, t) = 0$, and the corresponding determinant condition becomes $\det(\mathbf{M}_{sp}) = 0$. Thus, the hydraulic state of the surface is an essential component of the mathematical problem rather than an auxiliary assumption.

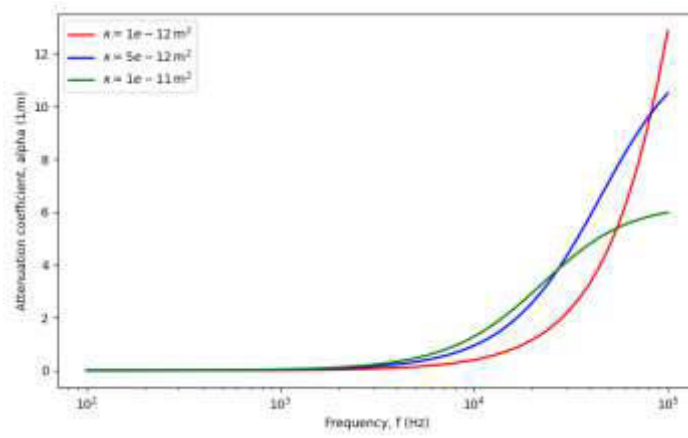


Figure 1. Representative attenuation curves for different permeability values.

The secular equation generally yields a complex wavenumber or complex phase velocity. Its real part characterizes the propagation speed, whereas its imaginary part describes attenuation. Thus, the main measurable wave characteristics may be expressed as $c = c(\omega, \varphi, \kappa, \eta)$ and $\alpha = \alpha(\omega, \varphi, \kappa, \eta)$, where φ is porosity, κ is permeability, η is fluid viscosity, and α is the attenuation coefficient. The representative curves in Figure 1 demonstrate the expected qualitative behavior: while attenuation increases noticeably as fluid–solid dissipative interaction becomes stronger.

The physical interpretation is that porosity changes the effective density, fluid volume fraction, and stiffness–mass balance of the two-phase medium. Permeability governs the ease of pore-fluid flow, whereas viscosity controls the resistance to relative motion between the fluid and the solid frame. Consequently, phase-velocity data are mainly informative for estimating elastic stiffness and porosity, while attenuation data are more sensitive to hydraulic transport properties and viscous dissipation.

Therefore, surface-wave diagnostics of saturated geomaterials should jointly use phase velocity and attenuation. Interpretation based only on phase velocity may be incomplete, since the hydraulic properties of the medium are primarily reflected in attenuation. In addition, open-pore, sealed-pore, and partially permeable surface conditions must be selected according to the actual physical state of the boundary. For practical applications, the present homogeneous isotropic model should be extended to layered, anisotropic, heterogeneous, and partially saturated media, while robust numerical algorithms are required for the stable solution of the complex secular equation.

In conclusion, the Rayleigh-wave problem in a fluid-saturated poroelastic half-space is reduced to the determination of a non-trivial, depth-decaying solution satisfying Biot’s coupled field equations and the free-surface boundary conditions. The potential representation decomposes the wave field into two compressional modes and one shear mode, while the boundary conditions lead to a secular determinant equation. The results confirm that poroelastic Rayleigh waves are inherently dispersive and attenuating, unlike classical Rayleigh waves in purely elastic media. Therefore, the joint analysis of their phase velocity and attenuation provides an effective theoretical and diagnostic basis for estimating the mechanical and hydraulic properties of saturated porous geomaterials.

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NUMERICAL INVESTIGATION OF A FOURTH-ORDER EQUATION FROM THIN FILM FLOW

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In this paper we consider the properties of solution of the fourth-order thin film equation

$$u_t = -\left(|u|^n u_{xxx}\right)_x, \quad x \in R, t > 0, \quad (1)$$

$$u(x, 0) = u_0(x), \quad x \in R \quad (2)$$

where $n \in \left(\frac{3}{2}, 2\right]$, $u(x, t)$ is the film height.

The fourth-order thin film equation (1) describes the dynamics of a viscous fluid spreading over a solid surface. It is derived from the Navier-Stokes equations in the lubrication approximation. Equation (1) appears as a more complicated doubly nonlinear degenerate parabolic model (see typical examples in [1, 2]) and has various applications in thin film dynamics, lubrication theory, and several other hydrodynamic-type problems.

Problem (1), (2) has been extensively studied by many authors (see [3–6] and references therein). These studies cover various numerical parameters, physical derivations of models, key mathematical results, and further applications.

In [3] studied countable set of self-similar solutions of the fourth-order porous medium equation

$$u_t = -\left(|u|^n u\right)_{xxxx}, \quad x \in R, t > 0, n > 0. \quad (3)$$

Authors considered eigenvalues and eigenfunctions of a nonlinear eigenvalue problem for (3).

This work focuses on the asymptotic behavior of self-similar solutions and a numerical investigation.

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МОДЕЛИРОВАНИЕ ПОКАЗАТЕЛЕЙ ЗАНЯТНОСТИ ТРУДОВЫХ РЕСУРСОВ СЕЛЬСКОГО ХОЗЯЙСТВА.

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Аннотация: Ключом исследования занятости трудовых ресурсов и их управления является математическая формулировка структуры населения и трудовых ресурсов.

Ключевые слова: трудовых ресурсов, математическая формулировка.

Экономика к рыночным отношениям порождает множество проблем. Среди них важнейшей является проблема занятости трудовых ресурсов. Для решения проблем обеспечения занятости трудовых ресурсов необходимо рассмотреть комплекс взаимосвязанных задач, связанных с исследованием современного состояния занятости трудовых ресурсов, выявлением основных показателей их занятости, изучением производственных процессов в сельскохозяйственных предприятиях и на этой основе определить потребности производства в них изучить и выявить потенциальные возможности трудовых ресурсов и сравнить ее с потребностями производства.

Ключом исследования занятости трудовых ресурсов и их управления является математическая формулировка структуры населения и трудовых ресурсов. Это осуществляется в следующие последовательности:

- математическая формулировка общей численности населения.
- математическая формулировка всего населения по полам.
- формулировка трудовых ресурсов.

Общая численность населения формулируется таким образом:

$$N = \{N_1, N_2\},$$

Где N_1 – множество, обозначающие работников мужского пола.

N_2 - множество, , обозначающие работников женского пола.

Отсюда

$$\begin{aligned} N_1 &= \{N_{11}, N_{12}, \dots, N_{1n}\} \\ N_2 &= \{N_{21}, N_{22}, \dots, N_{2n}\} \end{aligned}$$

Одним из основных показателей является годовой фонд рабочего времени работников. Максимального число годового фонда рабочего времени одного работника или возможная занятость работника в течение года с учетом законодательных актов труде определяется следующим образом:

Работники перерабатывающих отраслей работают сезонно. В Ташкентской области сезон продолжается с мая до конца декабря или января в зависимости от вида перерабатываемой продукции. Начиная с января до мая осуществляется ремонт помещения, механизмов и основная масса работников уходит в отпуск. С размещением цитрусовых в хозяйстве и переработкой его продукции можно организовать круглогодичную переработку с/х продукции. Но в Узбекистане перерабатывать цитрусовое во многих случаях не эффективно нежели их сразу продавать.

Таким образом рассмотрев значения Φ_1 , Φ_2 можно судить о занятости работников в каждой отрасли в зависимости от специфики отрасли природно-климатической условий.

1. Степень вовлечения трудовых ресурсов в сфере общественного производства определяется выражением

$$S_1 = \Phi_{\text{рх}}^{\Gamma} / \Phi^{\Gamma}$$

2. Определение степени участия трудоспособных работников, подростков, пенсионеров в общественном производстве играет значительную роль при исследовании занятости трудовых ресурсов. Не зная численного значения степени участия в ретроспективном периоде нельзя анализировать эффективность использования и занятости трудовых ресурсов.

1.
$$S_{1j} = \frac{\sum_m^n \sum_d^n A_{md}}{(N_j - \bar{N}_j) * \Phi_j}$$

$$S_{2j} = \frac{\sum_m^n \sum_d^n \bar{A} md}{(N_j - \bar{N}_j) * \Phi_j},$$

Где S_{1j} – степень участия трудоспособных работников относительно фактически отработанного времени;

S_{2j} – степень участия трудоспособных работников относительно фактически отработанных норм;

$Amdj$ – число фактические отработанных дней трудоспособными работниками в m -месяц, в d —дни, и в j - отрасли.

$\bar{A} mdj$ – число фактические отработанных норм трудоспособными работниками в m -месяц, в d —дни, и в j - отрасли.

N_j – число фактически трудоспособных работников j -й отрасли.

$\bar{N}_j$ – число фактически трудоспособных работников не выработавших ни одного человека дня .

Одним из важных показателей занятости трудовых ресурсов является активность работников. Разделив фактические отработанные нормы на фактически отработанной дней получим среде отработанной нормы работников в отработанной дней:

$$H_j = \frac{\sum_m \sum_d \bar{A} pmdj}{\sum_m \sum_d \bar{A} mdj}$$

Здесь H_j – интенсивность выработки норм работников в J -й отрасли.

Таким образом определение численных значений показателей занятости трудовых ресурсов в с/х предприятиях дает возможность выявить не использованные резервы по повышению эффективности с/х производства и благосостояния население сельской местности а также улучшения организации и использования труда по периодам года.

МАҲАЛЛАДА АҲОЛИ БАНДЛИГИНИ ТАЪМИНЛАНИШНИ МОДЕЛЛАШТИРИШ.

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Аннотация: Хизмат кўрсатиш ва сервис соҳасини жадал ривожлантириш учун кўлай широт яратиш, унинг иқтисодиётдаги улушини ошириш, хизмат кўрсатиш соҳа тармоқларида банд бўлганлар сонини кўпайтириш ва шу асосда аҳоли даромадларини ошириш ҳамда ички истеъмол бозорини замонавий, сифатли турли-туман хизмат турлари билан тулдириш.

Калит сўзлар: меҳнат ресурслари, математика шакиллантириш.

Аннотация: Создание благоприятных условий для быстрого развития сферы услуг, увеличения ее доли в экономике, увеличения количества занятых в сфере услуг и увеличения на этой основе доходов населения, а также наполнения внутреннего потребительского рынка современные, качественные разнообразные виды услуг.

Ключевые слова: трудовых ресурсов, математическая формулировка.

Annotation: Creating favorable conditions for the rapid development of the service sector, increasing its share in the economy, increasing the number of people employed in the service sector and increasing the income of the population on this basis, as well as filling the domestic consumer market with modern, high-quality various types of services.

Keywords: labor resources, mathematical formulation.

Мамлакатимизда амалга оширилаётган ислохотлар, ислохатлар учун эмас, балки инсонлар, уларнинг муносиб турмуш шароитини яхшилашга, ижтимоий ҳимоясини кучайтиришга қаратилганлигини Президентимизнинг ҳалқимиз фаровонлигини ошириш, ишсизликни камайтириш, аҳолини кексалик ёшида пенсия билан таъминлаш, уларни ижтимоий муҳофаза қилиш борасида узлуксиз ғамхурлик қилиб келаётганлигида кўриш мумкин. Буларнинг ҳаммаси аҳолини иш билан таъминлашга, тадбиркорликни ривожлантиришга, хўжалик юритувчи субъектлар сонини кўпайтиришга, эркин

иктисодиётни шакллантиришга, мамлакатимизда ижтимоий иқтисодий барқарорликни таъминлашга қаратилгандир.

Шуни таъкидлаш керакки, сўнгги йилларда хизмат кўрсатиш ва сервис соҳасини ривожлантириш бўйича изчил чоралар кўрилмоқда.

Хизматлар бозори таркиби хизматларнинг янги истиқболли турлари банк-молия, суғурта, ахборот-коммуникация хизматларини ва бошқаларни ривожлантириш ҳисобига такомиллашиб бормоқда. Оилаларни мураккаб маиший техника, компьютерлар ва шахсий автотранспорт билан таъмиллашнинг кескин ошиши уларга кўрсатилаётган хизматларнинг жадаллик билан кўпайишига имкон яратди.

Аммо, тан олиш керакки, ҳақиқатда мазкур соҳани ривожлантиришда жиддий камчиликлар ҳам йуқ эмас. Айниқса, бандликни ошириш ва аҳоли даромадларини кўпайтириш ҳамда маҳаллий бюджетларни тўлдиришнинг истиқболли манбаи сифатида хизмат кўрсатиш ва сервис имкониятларидан кам фойдаланилмоқда. Хизмат кўрсатиш соҳаси айниқса қишлоқ жойларда жуда суст ривожланмоқда.

Бозор муносабатлари шароитида ушбу соҳа жуда тез ривож топадиган соҳалардан биридир. Чунки, шуни эътироф этиш керакки, ушбу соҳа жуда катта маблағ талаб қилмайдиган, кичик ва хусусий тадбиркорликка мос ва жуда тез ривожланиши мумкин бўлган соҳадир.

Бундай катта имкониятдан фойдаланиш даражаси талаб қилинган ҳолатдан анча кам. Ушбу соҳанинг яна бир муҳим жиҳати, қишлоқда ортиқча иш кучини иш билан таъминлаш масаласини ҳам ҳал қилишга кумаклашувчи муҳим соҳа эканлигини ҳам ёддан чиқармаслик керак. Чунки хусусий тадбиркорлик учун жазибадор бўлган кўпгина анъанавий хизмат турлари шаҳарда ҳам қишлоқда ҳам етарли даражада ривожланмаяпти. Айниқса, қишлоқ жойларда бу соҳанинг ривожланиши учун ҳеч қандай таъсирчан чоралар кўрилмасдан келинди. Шу туфайли Маҳаллий ҳокимият органлари раҳбарлари бу муҳим тармоққа керакли даражада эътибор қаратмаётганлиги такидланди. Дунёнинг ривожланган мамлакатларида хизмат кўрсатувчи тармоқларининг янги ички маҳсулотдаги улуши 60-80 фоизни ташкил этади. Ушбу мамлакатларда иқтисодиётда банд булган аҳолининг 70 фоизи шу хизмат кўрсатиш соҳасида фаолият кўрсатади.

Аҳолининг сиёсий фаоллигини оширишга, ижтимоий ҳаётни янада демократлаштиришга қаратилган «Қонун лойиҳаларининг умумхалқ муҳокамаси тўғрисида»ги қонун қабул қилинди ва у жаҳон парламентаризми амалиётида ўз йўналиши бўйича дастлабки қонунлардан бири бўлиб қолди. «Норматив-ҳуқуқий ҳужжатлар тўғрисида»ги қонун ҳуқуқий давлат принципларини амалга оширишда катта аҳамиятга эга. Парламент томонидан қабул қилинган «Ўзбекистон Республикасининг референдуми тўғрисида»ги қонуннинг янги таҳрири халқ ҳокимиятчилиги амалга оширилишини ҳуқуқий жиҳатдан таъминлашга, референдумга — жамият ва давлат ҳаётининг энг муҳим масалалари бўйича фуқароларнинг умумхалқ овоз беришига тайёргарлик кўриш ҳамда уни ўтказиш механизмини такомиллаштиришга қаратилгандир. Янги таҳрирдаги мазкур қонун сайлов тўғрисидаги қонунларга, шу соҳадаги халқаро нормалар ва стандартларга мувофиқлаштирилди. Бу ҳужжатлар фуқароларнинг конституциявий ҳуқуқ ва эркинликларини ошириш мақсадида демократия анъаналари ривожланган мамлакатларнинг тарихий ҳамда замонавий қонунчилик тажрибаси асосида қабул қилинди.

Хизмат ва сервис соҳасини ривожланмаганлиги аҳолининг истеъмол ҳаражатлари таркибига ҳам таъсир қилади. Мамлакатимиз аҳолисининг истеъмол ҳаражатлар таркибида хизматларнинг улуши бор - йўғи 15,4 фоизни ташкил қилинади. Баҳолаб, ушбу кўрсаткичнинг миқдори ривожланган мамлакатларда 50-60 фоиздан кам эмас.

Ушбу ҳолатларни инобатга олиниб, хизматлар кўрсатиш ва сервис соҳасини жадал ривожлантириш учун қўлай широт яратиш, унинг иқтисодиётдаги улушини ошириш, хизмат кўрсатиш соҳа тармоқларида банд бўлганлар сонини кўпайтириш ва шу асосда аҳоли даромадларини ошириш ҳамда ички истеъмол бозорини замонавий, сифатли турли-туман хизмат турлари билан тўлдириш аниқ чора тадбирлари белгиланган.

Меҳнат бозори сегментациясини ўрганишда одатда учта белгидан фойдаланилади: касбий-тармоқ, малака-иш ҳақи ва ижтимоий-демографик. Бу белгиларни бириктириш орқали ходимлар фаолияти соҳасининг устуворлиги ҳамда моддий таъминланганлик даражаси билан фарқланувчи турли гуруҳларни ажратиш мумкин:

- иш билан бандлик кафолатларининг даражаси анчагина юқори ва даромадларнинг ўсиши инфляция ҳамда умумий иқтисодий ўсишдан ортиқ бўлган ривожланаётган тармоқ ва фаолият соҳаларида банд бўлган нодир юқори малакали ходимлар гуруҳи;
- иш билан бандлик кафолатлари йўқ ёки кам бўлган ва даромадлар инфляция суръатлари билан қиёсланадиган даражада бўлган қисқараётган ёки ривожланмаётган фаолият соҳаларидаги ортиқча юқори малакали ходимлар гуруҳи;
- иш билан бандлик нисбатан барқарор, даромадлар даражаси инфляция суръатидан оғда қолаётган, ижтимоий қувватланишга муҳтож бўлган ривожланаётган фаолият соҳаларидаги нодир малакали ва паст малакали ходимлар гуруҳи;
- иш билан бандлик кафолатлари йўқ ёки кам бўлган ва даромадлар даражаси инфляция суръатидан анча оғда қолаётган, қисқараётган ёки ривожланмаётган фаолият соҳаларидаги ортиқча малакали ва паст малакали ходимлар гуруҳи;
- юқорида айтилган тоифаларнинг ҳар қандайига мансуб бўлган, аммо айни вақтда ижтимоий заиф гуруҳлар қаторига кирадиган, меҳнат потенциалидан фойдаланиш имкониятлари чекланганлиги туфайли бандлик кафолатлари ва даромадлар даражаси у ёки бу меъёрга паст бўладиган ходимлар.

Мамлакатимизда хизматлар кўрсатиш ва сервис соҳасини жадал ривожлантиришнинг концептуал йўналишлари қўйдагилардин иборат бўлади:

1. Хизматлар кўрсатиш соҳасида тадбиркорликнинг фаоллигини янада кўчайтириш учун қулай шароит яратиш, хусусан, бу борадаги расмийчилик тусиқларини бартараф этиш вазифаси қўйилган.

2. Хизматлар ҳажмини юқори суръатларда ўсишини таъминлаш ва уларнинг ялпи ички маҳсулотни 70 фоизга етказиш.

3. Хизматлар ва сервис соҳасида банд бўлган аҳолининг сонини кўпайтириш.

4. Маҳаллада хизмат ва сервис соҳасини жадал ривожлантириш, хусусан, маҳалла аҳолисига кўрсатилаётган хизматлар, биринчи навбатда, коммунал-маиший, уй-жойларни таъмирлаш ва куриш.

5. Мамлакатимизда анъанавий хизматлар турларини ривожлантириш, айрим бугунги кун талабига жавоб берадиган, аммо унитилиб кетилган хизмат турларини излаб топиш ва уларни тиклаш.

6. Хизматларнинг янги истикболли турларини, хусусан, юридик, банк, молия, суғурта, лизинг ва бошқаларини жадал равишда ривожлантириш.

7. Мамлакатимизнинг хизматлар экспортини кўпайтириш учун ушбу соҳа корхоналарининг ҳалқаро бозордаги хизматлар даражаси ва сифатини оширишга эришиш.

8. Энг муҳими, хизматлар кўрсатиш ва сервис соҳасида ишлайдиган кадрларни тайёрлаш, қайта тайёрлаш ва малакасини оширишни ҳар томонлама қўллаб-қувватлаш.

Белгиланган ҳар бир тадбир, ушбу соҳани ривожлантириш учун муҳим аҳамиятга эга. Шу туфайли ушбу тадбирларни беками куст бажариш учун хизматлар кўрсатиш ва сервис соҳасини ривожлантириш дастури ишлаб чиқилган.

Шундай қилиб, ижтимоий муҳофаза одамларнинг турмуш даражаси билан ҳамбарчас боғланган бўлиб, у бир неча омилларни: саломатлик, демографик шароит, озиқ-овқат, кийим-кечак, истеъмол ва жамғариш фондларини, меҳнат қилиш шароитлари, иш билан бандлик, меҳнатни ташкил этиш, таълим олишни, уй-жойни, ижтимоий таъминот ва инсон эркинликларини ўз ичига олади.

BO'LAKLI UZLUKSIZ ARGUMENTLI TO'LQIN TARQALISH TENGLAMASI UCHUN BOSHLANG'ICH-CHEGARAVIY MASALANING KORREKTLIGI

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Hozirgi kunda matematik fizika tenglamalari yordamida murakkab dinamik jarayonlarni modellashtirish masalasi dolzarb ilmiy yo'nalishlardan biri hisoblanadi. Ayniqsa, to'lqin tarqalish jarayonlarini ifodalovchi giperbolik tipdagi tenglamalar turli sohalarida mexanika, akustika, elektromagnit hodisalar nazariyasi hamda muhandislik tizimlarida keng qo'llaniladi. Klassik to'lqin tenglamalari ko'pincha uzluksiz vaqt va fazo o'zgaruvchilariga bog'liq bo'lgan ideal tizimlarni tavsiflaydi. Biroq real jarayonlarda ko'pincha uzluksizlik buziladi, ya'ni tizim holati ma'lum vaqt oralig'ida keskin yoki diskret o'zgarishlarga duch keladi.

Shu nuqtai nazardan, bo'lakli uzluksiz argumentli differensial tenglamalar sinfi muhim ahamiyat kasb etadi. Bunday tenglamalarda noma'lum funksiya qiymati vaqtning butun qismi orqali aniqlanadigan diskret momentlarga ham bog'liq bo'ladi. Bu esa tizimning o'tgan holatlariga bog'liqligini aks ettiradi va modelni real jarayonlarga yaqinlashtiradi. Ayniqsa, signal uzatish tizimlari, biologik populyatsiyalar dinamikasi hamda boshqaruv nazariyasida kechikishli ta'sirlarni hisobga olish zarurati bunday tenglamalarning amaliy ahamiyatini yanada oshiradi.

Mazkur ishda qarayotgan to'lqin tenglamasi nafaqat bo'lakli uzluksiz argumentga ega, balki qo'shimcha yuklangan hadlarni ham o'z ichiga oladi. Xususan, fazoviy hosilaning bo'lakli uzluksiz argumentdagi qiymati hamda tashqi kuchning diskret vaqtga bog'liqligi tenglama strukturasini murakkablashtiradi. Natijada, masala klassik boshlang'ich-chegaraviy masalalardan farqli ravishda yangi analitik yondashuvlarni talab qiladi.

Ushbu tadqiqotda bo'lakli uzluksiz argumentli bir jinsli bo'lmagan to'lqin tenglamasi uchun qo'yilgan boshlang'ich-chegaraviy masalani tadqiq etamiz:

$D = \{(x, t); x \in [0, 1], t \geq 0\}$ sohada quyidagi bo'lakli uzluksiz argumentli bir jinsli bo'lmagan to'lqin tenglamasi uchun qo'yilgan masalani qaraylik.

$$u_{tt}(x, t) = a^2 u_{xx}(x, t) + bu_{xx}(x, [t]) + q(t)u(x, t) + f(x, [t]) \quad (1)$$

$$u(x, 0) = \varphi(x), u_t(x, 0) = \psi(x), x \in [0, 1] \quad (2)$$

$$u(0, t) = u(1, t) = 0, t \geq 0. \quad (3)$$

Bu yerda: $f(x, [t])$ tashqi manba funksiyasi, $\varphi(x), \psi(x)$ va $q(t)$ berilgan funksiyalar.

Dastlab, boshlang'ich chegaraviy masalani tadqiq etamiz. Qo'yilgan masala yechimining mavjudligi spektral tahlil usuli hamda o'zgaruvchilarni ajratish usullari bilan qurilgan tegishli spektral masalaning xos funksiyalar sistemasi bo'yicha ortogonal qator yig'indisi ko'rinishida qidiramiz. Furiye usuli bilan bu masala ekvivalent integral tenglamalarga keltiriladi.

Bunda (1)-(3) masala uchun quyidagi teorema o'rinli.

Teorema. Faraz qilaylik, $\varphi(x) \in H_0^1(0, 1), \psi(x) \in L_2(0, 1), q(t) \in C([0, T]), f(x, [t]) \in L_2(0, 1)$ shartlar o'rinli bo'lsin, U holda (1)-(3) masalaning $u(x, t) \in C([0, +\infty); L_2(0, 1)) \cap C^1([0, +\infty); L_2(0, 1)) \cap L_2(0, +\infty); H_0^1(0, 1))$ sinfga tegishli yagona yechimi mavjud bo'ladi.

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SUYUQLIKKA TO‘YINGAN G‘OVAK-ELASTIK MUHITLARDA BO‘YLAMA VA KO‘NDALANG TO‘LQINLARNI BIOT NAZARIYASI ASOSIDA SONLI MODELLASHTIRISH

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Annotatsiya

Ushbu tadqiqotda Biot klassik nazariyasi asosida suyuqlikka to‘yingan g‘ovak-elastik muhitlarda tez bo‘ylama (P1), sekin bo‘ylama (P2) va ko‘ndalang (S) to‘lqinlar tarqalishini modellashtirish uchun ikkinchi tartibli aniq chekli ayirmalar usuli (Chekli ayirmalar usuli) ishlab chiqildi va tasdiqlandi. Uch turdagi to‘lqin uchun 5% dan past nisbiy xato aniqlandi. G‘ovaklik, o‘tkazuvchanlik, qovushqoqlik va chastotaning to‘lqin tezliklariga ta’siri tizimli parametrik tadqiqot orqali o‘rganildi.

Kalit so‘zlar: Biot nazariyasi, g‘ovak-elastik muhit, bo‘ylama to‘lqin, ko‘ndalang to‘lqin, chekli ayirmalar usuli, sonli modellashtirish, parametrik tadqiqot.

1. Introduction

Suyuqlikka to‘yingan g‘ovak-elastik muhitlarda to‘lqin tarqalishi geomexanika, neft-gaz muhandisligi, zilzilaga chidamlilik muhandisligi va okean muhandisligi kabi bir qator muhandislik va fizika sohalarida intensiv tadqiqotlar mavzusi bo‘lib kelmoqda. Mazkur hodisani to‘g‘ri modellashtirish quyidagih amaliy masalalarni hal etishda muhim ahamiyat kasb etadi: uglevodorod konlarini qidirishda seysmik ma’lumotlarni talqin qilish [1], poydevorlarning dinamik javobini bashorat qilish [2] va g‘ovak muhitlarning gidravlik xususiyatlarini masofadan aniqlash [3].

Biot [1, 2] tomonidan yaratilgan klassik nazariya suyuqlikka to‘yingan izotrop g‘ovak muhitda uchta mustaqil to‘lqin modining mavjudligini nazariy asosladi: tez bo‘ylama to‘lqin (P1), sekin bo‘ylama to‘lqin (P2) va ko‘ndalang to‘lqin (S). P1 to‘lqinida qattiq skelet va suyuqlik bir xil fazada birgalikda harakat qiladi. P2 to‘lqini past chastotalarda diffuziya tipidagi tarqalishga o‘tib, yuqori so‘nish koeffitsienti bilan tavsiflanadi. Ko‘ndalang to‘lqin S esa asosan qattiq skelet orqali tarqaladi va suyuqlik ta’siri minimal darajada qayd etiladi.

Mavjud chekli ayirmalar usuli tatbiqlarida [3, 4] Biot tenglamalarining to‘liq bog‘lanish va dissipatsiya a’zolari saqlab qolinmagan hamda uchta to‘lqin modi uchun tizimli parametrik tadqiqot o‘tkazilmagan. Mavjud adabiyotlar tahlilidan ma’lum bo‘ladiki, ushbu tadqiqot birinchi bo‘lib mazkur kamchiliklarni bir vaqtda bartaraf etadi.

2. Method

Biot [1] asosida bir o‘lchamli (1D) g‘ovak-elastik muhit uchun harakat tenglamalari quyidagi ko‘rinishda ifodalanadi:

$$P \frac{\partial^2 u}{\partial x^2} + Q \frac{\partial^2 U}{\partial x^2} = \rho_{11} \frac{\partial^2 u}{\partial t^2} + \rho_{12} \frac{\partial^2 U}{\partial t^2} + b \frac{\partial(u-U)}{\partial t} \quad (1)$$

$$Q \frac{\partial^2 u}{\partial x^2} + R \frac{\partial^2 U}{\partial x^2} = \rho_{12} \frac{\partial^2 u}{\partial t^2} + \rho_{22} \frac{\partial^2 U}{\partial t^2} - b \frac{\partial(u-U)}{\partial t} \quad (2)$$

bu yerda u, U [m] — mos ravishda qattiq skelet va suyuqlik siljish vektorlari; P, Q, R [Pa] — Biot elastik koeffitsientlari; $\rho_{11}, \rho_{12}, \rho_{22}$ [kg/m³] — massa koeffitsientlari; $b = \mu f \cdot n^2/k$ [Pa·s/m²] — viskoz qarshilik koeffitsienti.

(1)–(2) tenglamalarini Chekli ayirmalar usuli ga o'tkazishda fazoviy va vaqt hosilalari ikkinchi tartibli markaziy ayirmalar bilan almashtiriladi:

$$\frac{\partial^2 u}{\partial x^2} \approx \frac{u_{i+1}^n - 2u_i^n + u_{i-1}^n}{\Delta x^2} \quad (3)$$

$$\frac{\partial^2 u}{\partial t^2} \approx \frac{u_i^{n+1} - 2u_i^n + u_i^{n-1}}{\Delta t^2} \quad (4)$$

$$\frac{\partial(u-U)}{\partial t} \approx \frac{u_i^{n+1} - u_i^{n-1}}{2\Delta t} \quad (5)$$

(3)–(5) approksimatsiyalari (1)–(2) ga tatbiq etilganda $n+1$ darajadagi noma'lumlar uchun yangilash formulasi olinadi:

$$u_i^{n+1} = \frac{(\rho_{22} + \kappa)P_u - (\rho_{12} - \kappa)P_U}{D} \quad (6)$$

$$U_i^{n+1} = \frac{(\rho_{11} + \kappa)P_U - (\rho_{12} - \kappa)P_u}{D} \quad (7)$$

bu yerda $\kappa = b \cdot \Delta t / 2$ [kg/m³] — viskoz parametr; $D = (\rho_{11} + \kappa)(\rho_{22} + \kappa) - (\rho_{12} - \kappa)^2$ — sistema determinanti; P_u, P_x — fazoviy ayirmalardan hosil bo'lgan o'ng taraf vektorlari.

Von Neyman barqarorlik tahlili asosida KFL sharti aniqlanadi: $KFL = V_1 \cdot \Delta t / \Delta x \leq 1$, ushbu tadqiqotda $KFL = 0.174$ qiymati qabul qilinadi. Clayton-Engquist yutuvchi chegaraviy shart (ABC) soxta aks etishlarni samarali bartaraf etadi. Boshlang'ich shart sifatida $x_0 = 0.1L$ nuqtasida Gauss impuls ($A_0 = 10^{-6}$ m) qabul qilinadi. Etalon material sifatida suv bilan to'yingan Berea qumtoshi tanlanadi: $G = 6$ GPa, $K_s = 36$ GPa, $n = 0.20$, $k = 10^{-13}$ m², $\mu f = 10^{-3}$ Pa·s.

3. Result. 3.1. Chekli ayirmalar usuli natijalari Biot analitik yechimlari bilan taqqoslandi. 1-jadvalda keltirilgan natijalar ko'rsatadiki, barcha uch to'lqin rejimi uchun maksimal nisbiy xato 5% dan past darajada qayd etiladi.

1-jadval. Chekli ayirmalar usuli va analitik yechimlar taqqoslanishi

To'lqin turi	Analitik [m/s]	Chekli ayirmalar usuli [m/s]	Xato [%]	Tavsif
P1 — tez bo'ylama	3,481	3,409	2.07	Bir yo'nalishli harakat
P2 — sekin bo'ylama	512	498	2.73	Qarama- qarshi yo'nalish
S — ko'ndalang	2,107	2,074	1.57	Qattiq skelet orqali

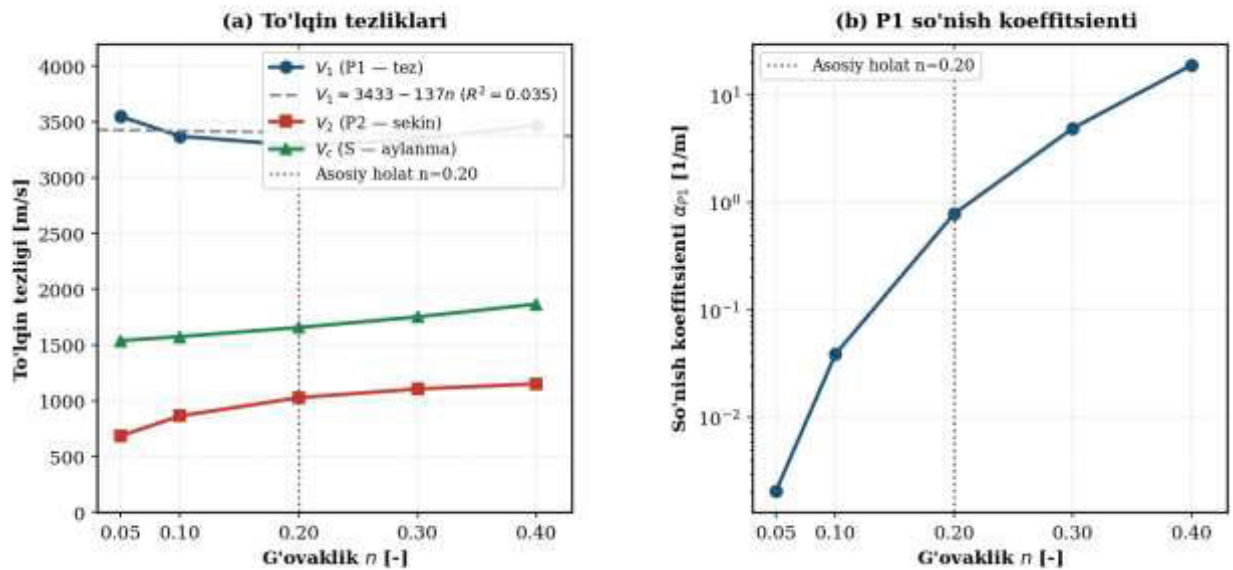
3.2. (i) G'ovaklik ta'siri: n ning 0.05 dan 0.40 gacha oshishi P1 tezligini 17.7% kamaytiradi. Empirik munosabat aniqlandi: $V_1 \approx 3912 - 1923n$ ($R^2 = 0.987$). Bu munosabat g'ovaklikni P1 tezligi o'lchovlari asosida teskari masala sifatida aniqlash imkonini beradi. P2 tezligi esa 218 dan 784 m/s gacha ortadi.

(ii) O'tkazuvchanlik ta'siri: P1 tezligi o'tkazuvchanlikka amalda sezgir emas ($<0.12\%$), P2 tezligi esa 201 dan 934 m/s gacha ortadi ($V_2 \propto k^{0.23}$). Mazkur differentsial sezgirlik P2 to'lqini o'lchovlari orqali g'ovak muhit o'tkazuvchanligini masofadan aniqlash imkonini beradi.

(iii) Qovushqoqlik ta'siri: P2 so'nish koeffitsienti μf ga to'g'ridan-to'g'ri proporsional ortadi ($\alpha P_2 \propto \mu f$), P1 ga ta'siri esa minimal ($<0.09\%$). Suv va neft uchun αP_2 qiymatlarining 5.9 marta farq qilishi suyuqlik turini masofadan farqlash imkonini beradi.

(iv) Chastota ta'siri: Past chastotalarda ($f < f_c$) P2 diffuziya rejimida tarqaladi, yuqori chastotalarda ($f > f_c$) haqiqiy tarqaladigan to'lqinga aylanadi. Setka konvergentsiya tahlili $O(\Delta x^2)$ fazoviy aniqlikni tasdiqladi.

1-rasm. G'ovaklikning to'lqin tezliklari va so'nish koeffitsientiga ta'siri



1-rasm. G'ovaklikning ta'siri: (a) P1, P2, S to'lqin tezliklari va chiziqli approksimatsiya; (b) P1 so'nish koeffitsienti.

4. XULOSALAR

Ushbu tadqiqotda quyidagi asosiy natijalarga erishildi:

1. Ishlab chiqilgan Chekli ayirmalar usuli sxemasi barcha uch to'lqin rejimini to'g'ri ifodalaydi. Barcha to'lqinlar uchun nisbiy xato 5% dan past: P1 uchun 2.07%, P2 uchun 2.73%, S uchun 1.57%.

2. G'ovaklikni oshirish P1 tezligini kamaytiradi: $V_1 \approx 3912 - 1923n$ ($R^2 = 0.987$). Mazkur empirik munosabat teskari masalani yechish imkonini beradi.

3. P1 tezligi o'tkazuvchanlikka amalda sezgir emas ($<0.12\%$), P2 tezligi esa kuchli sezgir ($V_2 \propto k^{0.23}$). Bu differentsial sezgirlik o'tkazuvchanlikni masofadan aniqlash uchun asos bo'lib xizmat qiladi.

4. P2 so'nishi μf ga proporsional ($\alpha_{P2} \propto \mu f$). Suv va neft α_{P2} qiymatlarining 5.9 marta farqi suyuqlik turini seysmik usul bilan farqlash imkonini beradi.

5. Olingan natijalar neft-gaz konlarini seysmik tavsiflanishi, aquifer o'tkazuvchanligini masofadan aniqlash va zilzilaga chidamlilik muhandisligida bevosita tatbiq etilishi mumkin.

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BIR JINSLI BO'LMAGAN NEFT FILTRATSIYA CHEGARAVIY MASALASI MATEMATIK MODELI VA UNI SONLI YECHISH

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TATU, QarshiDU, tayanch doktoranti.

Annotatsiya: Qatlam o'tkazuvchanlik parametriga nisbatan bo'lakl-bo'lakli g'ovak muhitda neft filtratsiya jarayoni matematik modeli qaralgan va chegaraviy masala shakllantirilgan hamda chekli-ayirmalar usulida yechilgan. Ishlab chiqilgan sonli model asosida hisoblash algoritmi va dasturiy ta'minot amalga oshirilgan, ular yordamida g'ovakli muhitda neft filtrlash jarayonlarini tadqiq qilish uchun bir qator hisoblash tajribalarini o'tkazilgan.

Kalit so'zlar: neft, filtratsiya, g'ovakli muhit, bo'lakli, o'tkazuvchanlik, chekli ayirmali usul, qatlam bosimi, sonli modellash tirish, hisoblash tajribasi.

Kirish. Ma'lumki, neft va gaz qatlamlarida bo'ladigan filtratsion jarayon ilmiy jihatdan o'rganish va uni tadqiq qilish ilmiy tadqiqot metodologiyasi bo'lgan matematik modellash tirish va hisoblash tajribalariga asoslanadi. Neft yoki gazlarning g'ovak muhitlardagi statsionar bo'lmagan filtratsiya jarayonining matematik modeli bir jinsli bo'lmagan parabolic differentsial tenglamalar uchun chegaraviy masala ko'rinishida ifodalanadi. Bunday chegaraviy masalalarni analitik ko'rinishda yechish murakkab jarayon bo'lib, ko'p hollarda oddiy hol uchun ham uning aniq yechimini topish juda murakkabdir.

O'tkazuvchanlik koeffitsienti bo'yicha bir jinsli bo'lmagan g'ovak muhitda neftning nostatsionar filtratsiya jarayonini qaraymiz. Qaralayotgan g'ovak muhitda neft harakatlanayotgan qatlam bir xil balandlikda h , uzunligi L , g'ovaklik koeffitsienti m , turli qildagi qiymatlarga ega bo'lgan o'tkazuvchanlik koeffitsienti k va qatlamning boshlang'ich bosimi $P_n > 0$ bo'lsin. Bo'lakli bir jinsli bo'lmagan qatlamdagi bosimni ifodalovchi funktsiyaning vaqt bo'yicha o'zgarishini aniqlash kerak. Bunda filtratsiya jarayonini ifodalovchi matematik model xususiy hosilali parabolik tipdagi differentsial tenglama ko'rinishida ifodalanadi [1-3]:

$$\beta \mu \frac{\partial P}{\partial t} = \frac{\partial}{\partial x} \left(k(x) \frac{\partial P}{\partial x} \right) - Q, \quad 0 < x, L. \quad (1)$$

Neft konlari asosiy ko'rsatkichlarini aniqlashda (1) differentsial tenglamani yechish uchun quyidagi boshlang'ich va chegaraviy shartlarni qaraymiz:

$$P(x, t) = P_H(x), \quad t = 0, \quad (2)$$

$$\frac{k}{\mu} \frac{\partial P}{\partial x} = \alpha(P - P_A), \quad x = 0, \quad (3)$$

$$\frac{k}{\mu} \frac{\partial P}{\partial x} = \alpha(P - P_A), \quad x = L, \quad (4)$$

$$Q = \sum_{i=1}^{N_q} \delta_i q_i, \quad \beta = m\beta_H + \beta_c.$$

Bu yerda n -chegaraga ichki normal; q_i -neft qudug'ining debiti; N_q -quduqlar soni; P - neft qatlamining bosimi; k -qatlamning o'tkazuvchanlik koeffitsienti; δ -Dirak delta funktsiyasi; μ -neftning qovushqoqlik koeffitsienti; β -elastiklik koeffitsienti $\beta = (\beta_c + m\beta_n)$; β_H - neftning siqilish koeffitsienti; β_c -qatlamning siqilish koeffitsienti; m -qatlamlar g'ovaklik koeffitsienti.

Chegaraviy masaladagi matematik modelning bizga aniq bo'lgan mavjud matematik modellardan farqli tomoni shundaki, bu yerda g'ovaklik koeffitsienti m va o'tkazuvchanlik koeffitsienti k bo'lakli bir jinsli qatlam uchun tushuniladi. G'ovak qatlam vertikal bo'yicha bir jinsli bo'lmaganligi sabab tenglamadagi $k(x)$ o'tkazuvchanlik koeffitsienti quyidagi oraliqlarda k_i qiymatlarni qabul qilishi mumkin

$$k(x) = \begin{cases} k_1, 0 \leq x \leq l_1, \\ k_2, l_1 < x \leq l_2, \\ \dots \dots \dots \\ k_n, l_{n-1} < x \leq 1. \end{cases}$$

Qo'yilgan chegaraviy masalani sonli modelashtirish uchun (1)-(4) chekli ayirmali ayirmali usuldan foydalanamiz va chegaraviy masalani o'lchamsiz masalaga keltiramiz. Buning uchun quyidagi belgilashlarni kiritamiz:

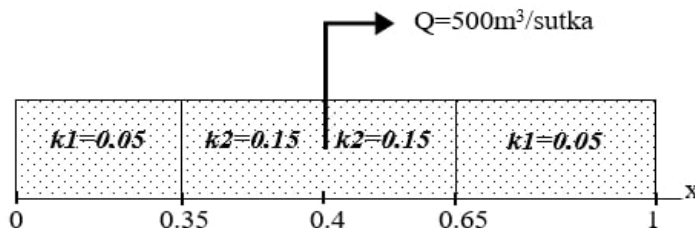
$$P^* = P / P_0; \quad x^* = x / L; \quad y^* = y / L; \quad k^* = k / k_0; \quad \tau = \frac{k_0 t}{\beta \mu L^2}; \quad q^* = \frac{Q \mu}{\pi k_0 P_0}.$$

Masalani o'lchamsiz ko'rinishga o'tkazamiz. Hosil bo'lgan chegaraviy masala chekli ayirmali usul bilan diskretlashtiriladi va vaqt bo'yicha qatlamlar uchun uch nuqtali tenglamalar sistemasiga keltiriladi.

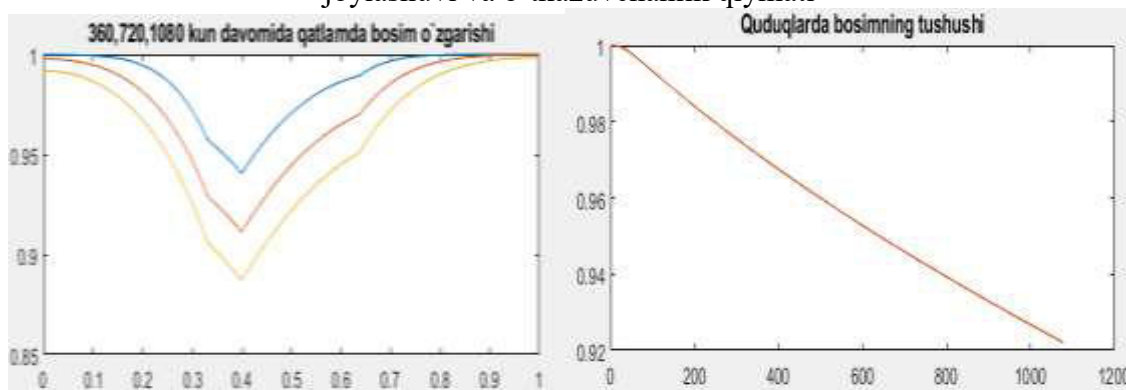
Hosil bo'lgan chekli ayirmali tenglamalar tizimi $l+1$ vaqt qatlamida haydash (progonka) usuli orqali yechilib, progonka koeffitsientlari yordamida bosim qiymatlari aniqlanadi va yechimning yaqinlashuv aniqligi ma'lum tartibda baholanadi[4-5].

Hisoblash eksperimenti. Bo'lakli-bir jinsli bo'lmagan qatlamning o'tkazuvchanlik koeffitsiyenti birinchi misolda, qatlam bitta quduqqa ega bo'lganda (1-2-rasm) bosim tarqalish grafiklari keltirilgan.

(1) - (4) chegaraviy masalani yechish uchun MatLab dasturiy vositasida hisoblash algoritmi va dasturi ishlab chiqildi. Qatlamdagi bosimning 360, 720 va 1080 sutka davomida taqsimlanish jarayoni hamda quduqlarda bosimning pasayishi aniqlanadi.



1-rasm. Bo'lakli-bir jinsli bo'lmagan qatlamda quduqning joylashuvi va o'tkazuvchanlik qiymati



2-rasm. Qatlamda bosim tarqalish dinamikasi va quduqdagi neft bosimining tushish grafigi

Rasmlardan ko'rinib turibdiki, o'tkazuvchanlik koeffitsiyentining turli qiymatlarida, ya'ni katta tarqoqlik bilan neft qatlamda bosimning taqsimlanishi kuzatilmoqda. Olingan hisoblash natijalari shuni ko'rsatadiki, qatlamda bosimning tarqalish tezligi o'tkazuvchanlik koeffitsiyenti katta bo'lgan zonalarida ortadi. Ushbu rasmlarda quduq atrofida bosimning pasayishi kuzatiladi, chunki quduq atrofida o'tkazuvchanlik koeffitsiyenti kichik qiymatga ega.

Ushbu hisoblash tajribalaridan quyidagi xulosalarni chiqarish mumkin: qatlamda o'tkazuvchanlik kichik qiymatlarida bosimning taqsimlanishi sekin bo'ladi, quduqlarda esa bosimning pasayishi kuchayadi (2-rasm). Bu esa neftning quduqqa yanada tezroq oqib kelishini va quduq atrofida tez to'planishini keltirib chiqaradi.

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QISHLOQ XO‘JALIGINI AVTOMATLASHTIRISHDA SUN‘IY INTELLEKT VA LORAWAN TARMOQLARINING MATEMATIK MODELLARI

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Kirish va muammoning dolzarbligi: Iqlim o‘zgarishi va suv resurslarining kamayishi sharoitida qishloq xo‘jaligini avtomatlashtirish eng ustuvor vazifalardan biridir. Hozirgi kunda tuproq namligini o‘lchaydigan oddiy datchiklarga asoslangan baza tizimlari texnologik jihatdan yangilik emas va ular murakkab iqlim o‘zgarishlariga yetarlicha moslasha olmaydi [1]. Shu sababli, zamonaviy ilmiy yondashuvlar oddiy sensorli boshqaruvdan voz kechib, ma’lumotlarni uzoq masofaga kam energiya sarflab uzatuvchi LoRaWAN tarmoqlari hamda sun‘iy intellekt (SI) asosidagi bashoratli modellashtirish (predictive modeling) texnologiyalariga qaratilmoqda. Ushbu tadqiqotning maqsadi aqlli sug‘orish tizimlarida ma’lumotlar uzatish va optimallashtirish jarayonlarining matematik modellarini ishlab chiqishdan iborat.

Metodologiya va matematik modellashtirish

Aqlli agro-tizimlarni loyihalashda kompleks matematik modellashtirish asosan ikki yo‘nalishda amalga oshiriladi:

1. LoRaWAN tarmog‘ida ma’lumotlar uzatishni modellashtirish (Signal so‘nishi):

Katta qishloq xo‘jaligi maydonlarida tarmoq tugunlari (sensorlar) va shlyuz (gateway) orasidagi signal so‘nishini (path loss) to‘g‘ri hisoblash uzluksiz aloqani ta’minlaydi. Ochiq maydonlar uchun radioto‘lqinlarning tarqalish dinamikasi Logarifmik-masofa (Log-distance path loss) modeli asosida quyidagicha modellashtiriladi [2]:

$$PL(d) = PL(d_0) + 10n \log_{10} \left(\frac{d}{d_0} \right) + X_{\sigma}$$

Bu yerda:

- $PL(d)$ — d masofadagi umumiy signal yo‘qotilishi (dB);
- $PL(d_0)$ — tayanch masofadagi (d_0) yo‘qotilish ko‘rsatkichi;
- n — qishloq xo‘jaligi muhitiga bog‘liq bo‘lgan signal so‘nish koeffitsiyenti (ochiq dalalar uchun odatda $n \approx 2.0 - 2.5$);
- X_{σ} — o‘simlik qoplam yoki relyefdagi o‘zgarishlar tufayli yuzaga keluvchi, nol o‘rtacha qiymatga ega bo‘lgan Gaus taqsimotidagi tasodifiy o‘zgaruvchi.

Ushbu tenglama maydonga qancha datchik va qayerda o‘rnatilishi kerakligini hudud topologiyasidan kelib chiqib aniq hisoblash imkonini beradi.

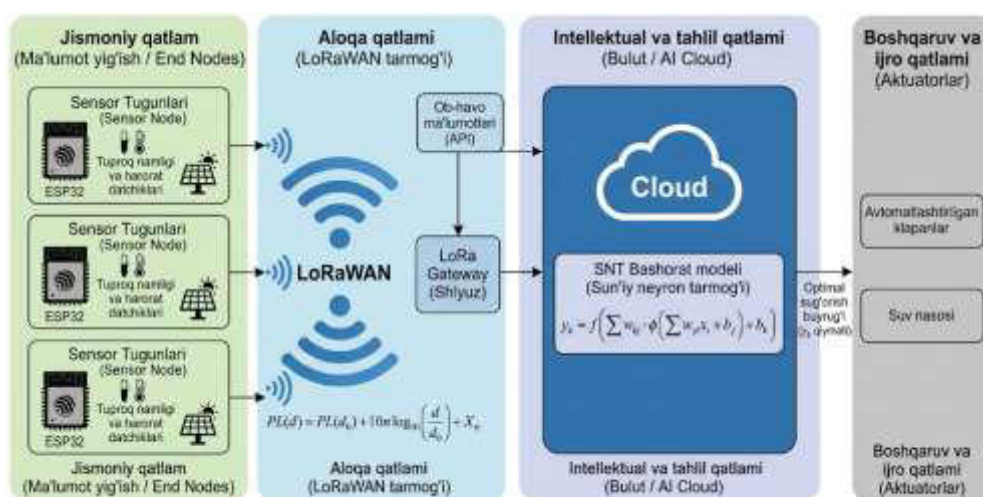
2. Sun'iy intellekt asosida sug'orishni bashorat qilish (SNT modeli):

Tizim oddiy “namlik tushsa suv ochiladi” (trigger) algoritmgiga emas, balki Sun'iy neyron tarmoqlariga (SNT) asoslangan ko'p o'lchovli bashorat modeliga tayanadi. Sug'orish uchun zarur bo'lgan suv hajmini aniqlash chiziqli bo'lmagan funksiya sifatida quyidagicha ifodalanadi [3]:

$$y_k = f \left(\sum_{j=1}^m w_{kj}^{(2)} \cdot \phi \left(\sum_{i=1}^n w_{ji}^{(1)} x_i + b_j^{(1)} \right) + b_k^{(2)} \right)$$

Bu yerda:

- x_i — tizimga kiruvchi vektor parametrlar (tuproq namligi, havo harorati, shamol tezligi va yog'ingarchilik ehtimoli);
- $w_{ji}^{(1)}$ va $w_{kj}^{(2)}$ — mos ravishda yashirin (hidden) va chiquvchi (output) qatlamlardagi vazn (weight) koeffitsiyentlari;
- $b_j^{(1)}$ va $b_k^{(2)}$ — neyron tarmog'ining og'ish (bias) koeffitsiyentlari;
- ϕ va f — ma'lumotlarni qayta ishlashdagi aktivlashtirish funksiyalari (odatda *ReLU* va *Sigmoid*);
- y_k — bashorat qilinayotgan yakuniy qiymat (ya'ni, ekinga aynan shu vaqtda qancha litr suv kerakligi).



1-rasm. LoRaWAN va Sun'iy intellekt algoritmlari integratsiyasiga asoslangan bashoratli sug'orish tizimining axborot oqimi arxitekturas.

Xulosa

Oddiy namlik sensorlariga asoslangan tizimlar zamonaviy innovatsion talablarga to'la javob bermasligini inobatga olib, qishloq xo'jaligida SI va LoRaWAN texnologiyalarining integratsiyasi chuqur matematik modellashirishni talab etadi. Taklif etilayotgan bashoratli SNT modellari (chiziqli bo'lmagan regressiya) va signal tarqalishining matematik tahlili suv resurslarini sarflashni minimallashtirib, hosildorlikni maksimallashtirish imkonini beradi. Ushbu modellar kelgusida murakkab IoT tizimlarini yaratish uchun tayanch konseptual asos bo'lib xizmat qiladi.

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ИССЛЕДОВАНИЕ КАЧЕСТВЕННЫХ СВОЙСТВ РЕШЕНИЙ ДВОЙНОЙ НЕЛИНЕЙНОЙ ПАРАБОЛИЧЕСКОЙ СИСТЕМЫ С ИСТОЧНИКОМ

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Аннотация. Работа посвящена исследованию математических моделей процессов реакции–диффузии, описываемых системами нелинейных параболических уравнений с переменной плотностью. В исследовании используются методы нелинейной декомпозиции (расщепления) и метод эталонных уравнений, позволяющие анализировать качественные свойства решений и получать их априорные оценки.

Многие процессы, возникающие в прикладных науках, могут быть успешно описаны и исследованы с помощью математических моделей, основанных на дифференциальных уравнениях и системах уравнений в частных производных. Такие модели широко используются при изучении явлений в физике, механике сплошных сред, химии, биологии, геофизике и других областях науки и техники. Математическое моделирование позволяет выявить основные закономерности протекания процессов, исследовать влияние различных параметров и предсказывать поведение системы при изменении внешних условий.

Рассмотрим в области $Q = \{(t, x) : t > 0, x \in R^N\}$ качественные свойства решений задачи Коши для следующей нелинейной системы уравнений реакции-диффузии

$$L_1(u, v) \equiv -\frac{\partial u}{\partial t} = \operatorname{div} \left(u^{m_1-1} |\nabla u^k|^{p-2} \nabla u \right) + \varepsilon u^{p_1} v^{q_1} = 0, \quad \varepsilon = \pm 1 \quad (1)$$

$$L_2(u, v) \equiv -\frac{\partial v}{\partial t} = \operatorname{div} \left(v^{m_2-1} |\nabla v^k|^{p-2} \nabla v \right) + \varepsilon u^{p_2} v^{q_2} = 0$$

$$u(0, x) = u_0(x) \geq 0, \quad v(0, x) = v_0(x) \geq 0, \quad x \in R^N \quad (2)$$

где, $k \in R$, $m_1, m_2 > 1$, $p_i, q_i \geq 1$, $p \geq 2$ — положительные действительные числа, $\nabla(\cdot) = \operatorname{grad}(\cdot)$ и $u_0(x) \geq 0, v_0(x) \geq 0$, является ограниченной, неотрицательной, нетривиальной, и достаточно гладкой функцией.

Исследование нелинейных уравнений и систем уравнений охватывает разнообразные направления, такие как изучение асимптотического поведения решений, вопросы существования и не существования решений, получение оценок, анализ уравнений высокого порядка и другие аспекты.

В последние десятилетия был получен ряд фундаментальных результатов, посвящённых исследованию нелинейных параболических уравнений и систем. Особый интерес представляют задачи, связанные с анализом глобальной разрешимости, разрушения решений за конечное время (blow-up) и определением критических показателей, разделяющих различные режимы поведения решений.

В работах многих авторов рассматривались различные классы вырождающихся и нелинейных параболических уравнений. В частности, значительный вклад в исследование подобных задач внесли результаты, посвящённые уравнению пористой среды и его обобщениям. Для этих моделей были установлены условия глобального существования решений, а также получены оценки, характеризующие их асимптотическое поведение.

Система уравнений (1) может рассматриваться как математическая модель совокупности физических процессов, происходящих в двухкомпонентных неоднородных нелинейных средах. К числу таких процессов относятся взаимосвязанные явления переноса и

взаимодействия, включая диффузию, теплопроводность, процессы горения, а также фильтрацию жидкостей и газов в пористых средах. В частности, рассматриваемая система может описывать процессы политропной фильтрации, возникающие при движении жидкостей и газов через пористые структуры при наличии внутренних источников или реакционных членов.

Кроме того, аналогичные математические модели используются при исследовании биологических процессов, связанных с переносом и взаимодействием различных веществ в биологических средах, а также при моделировании процессов распространения химических реагентов и тепловых эффектов в реакционно-диффузионных системах.

Таким образом, исследование качественных свойств решений системы (1)–(2) имеет не только теоретическое значение для развития теории нелинейных параболических уравнений, но и важное прикладное значение, поскольку позволяет более глубоко понять механизмы протекания сложных процессов переноса в неоднородных многокомпонентных средах.

В области, где $|\nabla u|=0$, $|\nabla v|=0$ или $u(t,x), v(t,x)=0$ задача (1)–(2) может не иметь классического решения [3; стр. 5–130]. Поэтому удовлетворение уравнению решения понимается в обобщенном смысле. Обобщенными являются, решения обладающие свойством непрерывности решения и потока, и удовлетворяющие интегральному тождеству.

Это связано с тем, что рассматриваемая система уравнений имеет нелинейный и вырождающийся характер, вследствие чего в некоторых точках области решения могут терять необходимую гладкость. В частности, в таких точках могут отсутствовать производные требуемого порядка, что делает невозможным применение классического определения решения дифференциального уравнения.

Следует отметить, что для вырождающихся нелинейных параболических уравнений и систем характерны специфические свойства, существенно отличающие их от классических линейных параболических моделей. В частности, такие системы могут обладать конечной скоростью распространения возмущений, что приводит к появлению свободных границ и ограниченных областей носителя решения. Это означает, что влияние начального возмущения распространяется не мгновенно по всей области, а лишь в некоторой ограниченной области пространства, граница которой со временем изменяется.

В связи с этим перед переходом к численным методам решения и визуализации процессов, описываемых системой уравнений (1), представляется необходимым провести детальный анализ качественных свойств решений. К числу наиболее важных характеристик относятся:

- конечная скорость распространения возмущений;
- локализация решений и эволюция области их носителя;
- асимптотическое поведение решений при больших значениях времени;
- структура и динамика фронта распространения в зависимости от параметров системы;
- влияние нелинейных источников и параметров среды на характер решений.

Задача (1)–(2) возникает в ряде прикладных областей и используется при математическом моделировании различных природных и технологических процессов [1–4] (см. также обзор в работе [4] и приведённую там библиографию). В частности, подобные модели применяются для описания процессов нелинейной диффузии в многокомпонентных средах, где взаимодействие различных компонентов приводит к появлению сложных нелинейных эффектов.

Система уравнений (1) может рассматриваться как математическая модель совокупности физических процессов, происходящих в двухкомпонентных неоднородных нелинейных средах. К числу таких процессов относятся взаимосвязанные явления переноса и взаимодействия, включая диффузию, теплопроводность, процессы горения, а также фильтрацию жидкостей и газов в пористых средах. В частности, рассматриваемая система может описывать процессы политропной фильтрации, возникающие при движении

жидкостей и газов через пористые структуры при наличии внутренних источников или реакционных членов.

Кроме того, аналогичные математические модели используются при исследовании биологических процессов, связанных с переносом и взаимодействием различных веществ в биологических средах, а также при моделировании процессов распространения химических реагентов и тепловых эффектов в реакционно-диффузионных системах.

Таким образом, исследование качественных свойств решений системы (1)–(2) имеет не только теоретическое значение для развития теории нелинейных параболических уравнений, но и важное прикладное значение, поскольку позволяет более глубоко понять механизмы протекания сложных процессов переноса в неоднородных многокомпонентных средах.

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APPLICATION OF CORRELATION-REGRESSION ANALYSIS METHODS FOR FORECASTING ANNUAL GAS CONSUMPTION IN QASHQADARYO REGION

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Abstract. This article examines the application of correlation and regression analysis methods for forecasting natural gas consumption in Qashqadaryo Region. The primary objective of the research is to analyze the dynamics of gas consumption based on existing statistical data, identify key influencing factors, and develop a precise economic-mathematical forecast for the upcoming period. The study employs time series analysis, compares various approximation functions, and evaluates model accuracy through the coefficient of determination (R^2) and the correlation coefficient (r).

Keywords: *Correlation, regression, econometric model, systematic approach, approximation, forecast.*

Introduction

The primary objective of the study is to analyze existing natural gas consumption indicators in Qashqadaryo Region through econometric methods, with the aim of developing economically substantiated mechanisms for energy resource utilization in the area, identifying the most critical factors influencing consumption patterns, and establishing a reliable foundation for making effective management decisions in the future.

Conclusion

In this scientific research, the problem of forecasting annual natural gas consumption in Qashqadaryo Region was investigated using correlation and regression analysis methods. During the research process, monthly natural gas consumption statistical data for 2025, provided by the "Hududgaz Qashqadaryo" gas supply branch, were analyzed. Based on the selected model, gas consumption volumes for the upcoming months (January, February, and March) were forecasted and compared with actual observed values. In conclusion, it has been scientifically substantiated that correlation and regression analysis methods demonstrate high efficiency in modeling and forecasting natural gas consumption in Qashqadaryo Region.

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KONSENTRIK SFERIK SIRTILAR BILAN CHEGARALANGAN G'OVAK-IZOTROPIK MUHITLI SOHADA NOSTATSIONAR TO'LQINLAR JARAYONI

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Annotatsiya: Ushbu ilmiy tatqiqot ishida konsentrik sferik sirtlar bilan chegaralangan suyuqlik bilan to'yingan g'ovak-izotropik muhitli sohada nostatsionar to'lqinlar bo'ylama to'lqin tarqalishi jarayoni haqidagi masala o'rganilgan. Masalani yechish algoritmini ishlab chiqishga o'lchovsiz vaqt bo'yicha Laplas integral almashirishlari qo'llanilgan. Tasvirlar fazosida masala to'rt noma'lumli tenglamalar sistemasini yechishga keltirilgan bo'lib, bu sistemaning yechimi eksponentalar bo'yicha cheksiz qatorlar shaklida topilgan. Qatorlar koeffitsiyentlariga nisbatan rekurrent munosabatlar hamda ular uchun boshlang'ich shartlar aniqlangan. Tasvirlar fazosida suyuqlik bilan to'yingan g'ovak-izotropik muhit nuqtalarida ko'chish vektori va kuchlanish tenzori komponentalari hamda ideal suyuqliklarning gidrodinamik xarakteristikalarini uchun formulalar olingan. Tasvirdan originalga o'tish kompleks o'zgaruvchili funksiyalar nazariyasidan funksiyaning qoldiqlari yordamida amalga oshirilgan. Olingan natijalarni yer osti inshootlarining mustahkamligini o'rganish va ularni loyihalashtirishda foydalanish mumkin.

Kirish. Uzlaksiz muhitda nostatsionar to'lqin jarayonlarini matematik modelashtirish va o'rganish to'lqin dinamikasining murakkab va shu bilan birga dolzarb sohasidir. Deformatsiyalanuvchi jismlarning to'lqin dinamikasi muammolarining dolzarbligi texnologiyaning turli sohalarining rivojlanishi, dinamik yuklar ostida ishlaydigan yangi tuzilmalarning yaratilishi, shuningdek, geofizika, seysmologiya, konchilik sanoati, fuqarolik va sanoat inshootlarini qurish muammolari bilan bog'liq.

Hozirgi vaqtda tutash muhitlarda to'lqinlarning tarqalishi va difraksiyasini o'rganishga bag'ishlangan ko'plab ilmiy maqolalar mavjud. Monografiyada [1] yupqa devorli va qattiq deformatsiyalanuvchi sferik jismlarning elastik va akustik muhit bilan nostatsionar o'zaro ta'siri muammosi bo'yicha tizimli tadqiqotlar natijalari keltirilgan. [2] ishida esa elastik yarim fazoda sferik bo'shliqdan nostatsionar to'lqinlarining tarqalishi o'rganilgan. Ko'chish vektori va kuchlanish tenzori komponentlari uchun formulalar olingan.

Masalaning qo'yilishi. Aytaylik, radiuslari a va b , ($a < b$) bo'lgan o'zaro konsentrik sferik sirtlar bilan chegaralangan hamda suyuqlik bilan to'yingan g'ovak-izotropik muhitli sferik qatlam berilgan bo'lsin. G'ovak-izotropik muhit harakati boshlang'ich nuqtasi sferik qatlam markazida bo'lgan (r, θ, φ) sferik koordinatalar sistemasida qaraladi.

Vaqtning $\tau = 0$ boshlang'ich momentidan boshlab ichki sferik qatlamning sirtiga o'qsimmetrik normal tekis $p_s(t)$ sirt kuchi ta'sir etadi.

$$\sigma_{rr}|_{r=a} = -(1-\gamma_0)p_s(t), \quad \sigma_m|_{r=a} = -\gamma_0 p_s(t) \quad (1)$$

Bu holda suyuqlik bilan to'yingan g'ovak-izotropik muhitda faqat ikkita bo'ylama to'lqin tarqaladi.

Sferik qatlamning tashqi sirti-erkin sirt, unda shartlar

$$\sigma_{rr}|_{r=b} = 0, \quad \sigma_m|_{r=b} = 0 \quad (2)$$

ko'rinishga ega bo'ladi.

Masalaning o'qsimmetrikligini etiborga olib, suyuqlik bilan to'yig'gan g'ovak-izotropik muhit muhitining harakati ϕ_κ potentsiallarga nisbatan to'lqin tenglamalari orqali tasvirlanadi ("0" indeks bilan qattiq qismdagi to'lqin potentsiali, "1" bilan esa suyuqlik qismidagi to'lqin potentsiali belgilangan):

$$\alpha_\kappa^2 \frac{\partial^2 \phi_\kappa}{\partial t^2} = \frac{\partial^2 \phi_\kappa}{\partial r^2} + \frac{2}{r} \frac{\partial \phi_\kappa}{\partial r}, \quad \kappa = 0, 1, \quad (3)$$

bu yerda $\Delta - (r, \theta, \varphi)$ sferik koordinatalar sistemasida Laplas operatori.

Vaqtning $\tau = 0$ boshlang'ich momentida qobiq va muhit tinch holatda bo'ladi, ya'ni boshlang'ich shartlar bir jinslidir

$$\phi_\kappa|_{t=0} = \frac{\partial \phi_\kappa}{\partial t}|_{t=0} = 0, \quad \kappa = 0, 1. \quad (4)$$

Masalaning yechish algoritmi: (1)-(4) boshlang'ich-chegaraviy masalani yechishga vaqt bo'yicha Laplas integral almashirishlari qo'llaniladi. Laplas almashirishlarining tasvirlar fazosida masala quyidagi

$$\begin{aligned} M_1(s)A^L(s)z^2t + F_1(s)B^L(s)t - M_1(s)B^L(s)z^2t + F_2(s)D^L(s)z &= k_1(s)zt, \\ N_1(s)A^L(s)x^2y + T_1(s)B^L(s)y - N_1(s)B^L(s)x^2y + T_2(s)D^L(s)x &= 0, \\ M_2(s)E^L(s)zt^2 + G_1(s)B^L(s)t - M_2(s)D^L(s)zt^2 + G_2(s)D^L(s)z &= k_2(s)zt, \\ N_2(s)E^L(s)xy^2 + U_1(s)B^L(s)y - N_2(s)D^L(s)xy^2 + U_2(s)D^L(s)x &= 0 \end{aligned}$$

to'rt noma'lumli tenglamalar sistemasini yechishga keltirilgan. Bu sistemaning yechimi eksponentalar bo'yicha cheksiz qatorlar shaklida izlanib, qatorlar koeffitsiyentlariga nisbatan rekurrent munosabatlar hamda ular uchun boshlang'ich shartlar olingan.

Tasvirlar fazosida suyuqlik bilan to'yingan g'ovak-izotropik muhit nuqtalarida ko'chish vektori va kuchlanish tenzori komponentalari hamda suyuqlik qismdagi bosim bosim uchun formulalar quyidagi ko'rinishga ega:

$$\begin{aligned} u_1^L &= -\frac{1}{r^2} \sum_{ijkl=0}^{\infty} \left\{ \left[R_{10}(r\alpha_0s)A^L(s)e^{-r\alpha_0s} + R_{10}(-r\alpha_0s)B^L(s)e^{r\alpha_0s} - R_{10}(r\alpha_0s)B^L(s)e^{-r\alpha_0s} \right] + \right. \\ &\quad \left. + \left[R_{10}(r\alpha_1s)E^L(s)e^{-r\alpha_1s} + R_{10}(-r\alpha_1s)D^L(s)e^{r\alpha_1s} - R_{10}(r\alpha_1s)D^L(s)e^{-r\alpha_1s} \right] \right\} x^i y^j z^{-k} t^{-l}, \\ \sigma_{rr}^L &= \frac{1}{r^3} \sum_{ijkl=0}^{\infty} \left\{ \left[Q_{100}(r\alpha_0s)a_{ijkl}(s)e^{-r\alpha_0s} + Q_{100}(-r\alpha_0s)b_{ijkl}(s)e^{r\alpha_0s} - Q_{100}(r\alpha_0s)b_{ijkl}(s)e^{-r\alpha_0s} \right] + \right. \\ &\quad \left. + \left[Q_{110}(r\alpha_1s)e_{ijkl}(s)e^{-r\alpha_1s} + Q_{110}(-r\alpha_1s)d_{ijkl}(s)e^{r\alpha_1s} - Q_{110}(r\alpha_1s)d_{ijkl}(s)e^{-r\alpha_1s} \right] \right\} x^i y^j z^{-k} t^{-l}, \\ \sigma_m^L &= \frac{1}{r^3} \sum_{ijkl=0}^{\infty} \left\{ \left[Q_{300}(r\alpha_0s)a_{ijkl}(s)e^{-r\alpha_0s} + Q_{300}(-r\alpha_0s)b_{ijkl}(s)e^{r\alpha_0s} - Q_{300}(r\alpha_0s)b_{ijkl}(s)e^{-r\alpha_0s} \right] + \right. \\ &\quad \left. + \left[Q_{310}(r\alpha_1s)e_{ijkl}(s)e^{-r\alpha_1s} + Q_{310}(-r\alpha_1s)d_{ijkl}(s)e^{r\alpha_1s} - Q_{310}(r\alpha_1s)d_{ijkl}(s)e^{-r\alpha_1s} \right] \right\} x^i y^j z^{-k} t^{-l}. \end{aligned}$$

Bu ifodalarning originallari topish qoldiqlar nazariyasi yordamida aniqlanadi [3].

Xulosa. Konsentrik sferik sirtlar bilan chegaralangan suyuqlik bilan to'yingan g'ovak-izotropik muhitli sohada nostatsionar to'lqinlar bo'ylama to'lqin tarqalishi jarayonini matematik tasvirlash bilan olingan boshlang'ich-chegaraviy masalaning yechish algoritmi ishlab chiqildi. Suyuqlik bilan to'yingan g'ovak-izotropik muhit kuchlanish-deformatsiya holati xarakteristikalarini uchun analitik formulalar olindi.

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ESTIMATES OF SELF-SIMILAR SOLUTIONS OF THE CAUCHY PROBLEM FOR A DIVERGENT REACTION-DIFFUSION SYSTEM WITH VARIABLE DENSITY

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Abstract: Using self-similar analysis of solutions, this paper investigates the Fujita-type problem of global solvability of solutions and estimates solutions to asymptotic self-similar solutions based on a numerical analysis of the solutions considered. A corresponding initial approximation is proposed that preserves solutions with refined properties.

The study of nonlinear differential equations and their systems occupies an important place in modern mathematics and its applications. Such equations arise in the modeling of various processes in physics, biology, and chemistry, as well as in problems of continuum mechanics and heat transfer theory. Therefore, considerable attention is paid to the existence, uniqueness, and qualitative properties of solutions to these problems. The study of nonlinear differential equations and partial differential systems is an important area of modern mathematical science.

We consider a problem described by the following equations in the domain $Q = \{(t, x) : 0 < t, x \in R^N\}$

$$\begin{aligned} L_3(u, v) &= -|x|^{-l} \frac{\partial u}{\partial t} + \operatorname{div} \left(|x|^n u^{m_1-1} |\nabla u^k|^{p-2} \nabla u \right) + |x|^{-l} \varepsilon u^{p_1} v^{q_1} = 0, \\ L_4(u, v) &= -|x|^{-l} \frac{\partial v}{\partial t} + \operatorname{div} \left(|x|^n v^{m_2-1} |\nabla v^k|^{p-2} \nabla v \right) + |x|^{-l} \varepsilon u^{p_2} v^{q_2} = 0, \end{aligned} \quad (1)$$

with initial condition

$$\begin{aligned} u(0, x) &= u_0(x) \geq 0, \\ v(0, x) &= v_0(x) \geq 0, \quad x \in R^N, \end{aligned} \quad (2)$$

where $n, l, k \in R, m_1 \geq 1, m_2 \geq 1, p_i, q_i \geq 1, p \geq 2$, are positive real numbers, $\nabla(\bullet) = \operatorname{grad}_x(\bullet)$, $x \in R^N$ and t are the spatial and temporal coordinates, respectively, and $u = u(t, x) \geq 0, v = v(t, x) \geq 0$ are the desired solutions.

The n and l numerical parameters characterize the variable permeability of a nonlinear medium. For $k=0$, equation system (1) describes the process of polytropic filtration with variable density in a nonlinear two-component medium in the presence of absorption and is called the system of equations for polytropic filtration in a two-component nonlinear medium.

In the case of problem (1)-(2) for one equation, it was studied in the work [1] and its eigenfunctions were investigated.

System (1) describes a variety of physical processes [1, 2], for example, reaction-diffusion processes, thermal conductivity, polytropic filtration of liquid and gas in a nonlinear medium in the presence of a source ($\varepsilon = +1$) or absorption ($\varepsilon = -1$) whose power is equal to $\varepsilon u^{p_i} v^{q_i}$, ($i = 1, 2$).

System of equations (1) exists in a domain where or . In this case, system of equations (1) has no meaning in the classical sense. Therefore, it is necessary to investigate the weak solution. Various qualitative properties, such as solution localization, the finite perturbation velocity, and the asymptotic behavior of the solutions and the front, which depend on the values of the parameters of system of equations (1), must be studied before visualizing the process and numerically solving the described system of equations (1).

Many authors have considered various classes of degenerate and nonlinear parabolic equations. In particular, results devoted to the porous media equation and its generalizations have made a significant contribution to the study of such problems. For these models, conditions for the global existence of solutions were established, and estimates characterizing their asymptotic behavior were obtained.

Several authors have considered various special cases of the following weakly coupled system [3,4]

$$\begin{cases} u_t = \Delta u + f(u, v) \\ v_t = \Delta v + g(u, v) \end{cases} \quad (x, t) \in D \times (0, T) \quad (3)$$

where f, g are real continuous functions for $u(x, t) \geq 0, v(x, t) \geq 0$ and C^1 for $u(x, t) > 0, v(x, t) > 0$.

In [5], the critical Fujita exponent for the following Cauchy problem was given as

$$\begin{aligned} u_t &= \Delta u^m + u^p, \quad x \in \mathbb{R}^N, \quad t > 0, \\ u(x, 0) &= u_0(x), \quad x \in \mathbb{R}^N, \end{aligned} \quad (4)$$

where $p > 1, m > 1$ or $1 > m > \frac{(N-2)}{N}$ и $u_0(x)$ — bounded positive continuous function.

They proved that blows up the solution $u(x, t)$ of equation (4) blows up global positive solutions exist if $1 < p < p_c$.

M. Escobedo and M. A. Hererro [3] investigated the initial problem for the system

$$\begin{cases} u_t = \Delta u + u^{p_1} \\ v_t = \Delta v + v^{p_2} \end{cases} \quad (x, t) \in \mathbb{R}^N \times (0, T) \quad (5)$$

$$u(x, 0) = u_0(x) \geq 0, \quad v(x, 0) = v_0(x) \geq 0, \quad x \in \mathbb{R}^N, \quad p_1 > 0, \quad p_2 > 0$$

They were interested in non-negative solutions that decay at infinity for a fixed t .

The motivation for considering such a system of equations is that it is a degenerate partial differential equation and therefore a source for the emergence of new nonlinear effects, such as the finite velocity of disturbance propagation, the spatial localization of bounded and unbounded solutions of which were first established in [6] for the particular value of the numerical parameters $n=q_i=p_i=0, k=1, p=2$.

To construct self-similar solutions to the system under consideration, the nonlinear splitting algorithm proposed in [5] is used. This approach allows us to reduce the original nonlinear system of partial differential equations to a system of equations of lower dimension, which significantly simplifies further analytical and numerical analysis.

To reduce equation (1) to a self-similar form, an appropriate self-similar transformation of the variables is introduced. As a result, the original system of equations is transformed into a system of ordinary differential equations with respect to the new unknown functions. To this end, we first consider the system of ordinary differential equations that determines the parameters of the self-similar transformation and describes the temporal evolution of the scaling functions.

For system (1) we obtain a self-similar system of equations and functions $f_1(\xi), f_2(\xi)$ that satisfy the following “radially” symmetric system

$$L_1(f_1, f_2) \equiv \xi^{1-s} \frac{d}{d\xi} \left(\xi^{s-1} f_1^{m_1-1} \left| \frac{df_1}{d\xi} \right|^{p-2} \frac{df_1}{d\xi} \right) + \frac{\xi}{p} \frac{df_1}{d\xi} + \frac{\alpha_1}{1-(k(p-2)+m_1-2)\alpha_1} (f_1 + \varepsilon f_1^{p_1} f_2^{q_1}) = 0, \quad (6)$$

$$L_2(f_1, f_2) \equiv \xi^{1-s} \frac{d}{d\xi} \left(\xi^{s-1} f_2^{m_2-1} \left| \frac{df_2}{d\xi} \right|^{p-2} \frac{df_2}{d\xi} \right) + \frac{\xi}{p} \frac{df_2}{d\xi} + \frac{\alpha_2}{1-(k(p-2)+m_2-2)\alpha_2} (f_2 + \varepsilon f_2^{p_2} f_1^{q_2}) = 0,$$

$$\text{If } (k(p-2)+m_1-2)\alpha_1 = (k(p-2)+m_2-2)\alpha_2 \quad (7)$$

Theorem 1. Suppose $p > n+l, \frac{\alpha_1}{1-(k(p-2)+m_1-1)\alpha_1} < \frac{s}{p}, \frac{\alpha_2}{1-(k(p-2)+m_2-1)\alpha_2} < \frac{s}{p},$

$m_i + k(p-2) - 2 > 0, i=1, 2, u_0(x) \leq u_1(0, x), v_0(x) \leq v_1(0, x), x \in R.$ Then for problem (1)-(2) there exists a global solution in , and for it the following estimate holds:

$$u(t, x) \leq u_1(t, x), \quad v(t, x) \leq v_1(t, x) \quad (8)$$

Then for problem (1)-(2) the phenomenon of finite velocity is valid, i.e. there exist continuous functions $l_1(t), l_2(t)$ such that $u(t, x) \equiv 0$ and $v(t, x) \equiv 0$ for $|x| \geq l_1(t)$ and $|x| \geq l_2(t)$, respectively.

where

$$u_1(t, x) = \bar{u}(t) \bar{f}_1(\xi), \quad v_1(t, x) = \bar{v}(t) \bar{f}_2(\xi), \quad (a)_+ = \max(0, a), \quad \xi = \frac{\varphi(|x|)}{\tau^p},$$

$$\bar{u}(t) = (T+t)^{-\alpha_1}, \quad \bar{v}(t) = (T+t)^{-\alpha_2}, \quad (9)$$

$$\bar{f}_1(\xi) = (a - \xi^\gamma)^{\gamma_1}, \quad \bar{f}_2(\xi) = (a - \xi^\gamma)^{\gamma_2}, \quad \varphi(|x|) = \frac{p}{p - (n+l)} |x|^{\frac{p - (n+l)}{p}}$$

Comparison methods allow us to compare solutions to the original problem with solutions to auxiliary problems for which the behavior of the solutions is known or can be investigated using simpler methods. This allows us to obtain a priori estimates of the solutions and determine the range of their possible values. Such estimates play an important role in studying the conditions for the existence and uniqueness of solutions, as well as in analyzing their global behavior.

Furthermore, such estimates are often used to prove the global solvability of a problem or to establish conditions for the occurrence of solution blowup in finite time. The results obtained are also of significant importance in the numerical study of nonlinear problems, as they allow us to verify the correctness of numerical methods and interpret the results of computational experiments.

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ISSIQXONA IQLIM PARAMETRLARINI BOSHQARISHDA MPC VA RL USULLARIDAN FOYDALANISH

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Annotatsiya

Mazkur tezisda issiqxonalarda mikroiklim parametrlarini samarali boshqarish masalasi ko‘rib chiqiladi. Harorat, namlik va karbonat angidrid konsentratsiyasi kabi parametrlarni optimallashtirishda zamonaviy boshqaruv usullari — MPC (Model Predictive Control — modelga asoslangan boshqaruv) va RL (Reinforcement Learning — mustahkamlovchi o‘rganish) algoritmlarining qo‘llanilishi tahlil qilinadi. Ushbu usullar yordamida energiya sarfini kamaytirish va o‘simliklar o‘sishi uchun optimal sharoit yaratish imkoniyatlari ko‘rsatib beriladi.

Kalit so‘zlar: issiqxona, mikroiklim boshqaruvi, MPC, RL, aqlli qishloq xo‘jaligi, optimallashtirish.

Asosiy qism

Hozirgi kunda olimlar tobora issiqxonalarga ekinlarni o'stirish sharoitlarini optimallashtirish uchun muhim joylar sifatida e'tibor qaratmoqda. Issiqxona sharoitlarini optimallashtirish asosan uning ichki mikroiklim parametrlarini — harorat, namlik, yorug'lik va CO_2 miqdorini to'g'ri boshqarishga bog'liq. Issiqxona iqlimini boshqarish ekin o'sishi va issiqxona iqlimining o'zgarishi kabi bir nechta jarayonlarni turli vaqt shkalalarida sodir bo'lishi bilan tavsiflanadi [1].

Biroq, boshqaruv vazifasi qiyin bo'lib, bu jarayon dinamikasi yuqori darajada nohiziq va murakkab. Shu bilan birga, temperatura va namlik kabi iqlim o'zgaruvchilari ekinlarga zarar yetkazishni to'xtatish uchun samarali chegaralangan bo'lishi lozim. Shu sababli issiqxona iqlimini boshqarishda an'anaviy usullardan foydalanish yetarli emas. Bunday tizimlarining o'rniga optimallashtiruvchi usullardan foydalanishning ko'plab sabablari mavjud. Bulardan biri murakkab va o'zgaruvchan sharoitlarda an'anaviy usullar yetarli darajada samarali ishlamasligi mumkin bo'lgan bir paytda sun'iy intellekt va optimallashtirishga asoslangan boshqaruv usullaridan foydalanish ancha effektiv [2].

MPC boshqaruv metodlari to'plamidan iborat bo'lib, u o'simlikning matematik modelidan foydalangan holda tizimning kelajakdagi xatti-harakatini bashorat qilishga asoslangan. Jarayon modellari asoslangan bir qancha MPC algoritmlari mavjud. Bu algoritmlar bir-biridan faqat tizim yoki tashqi ta'sirlar model strukturasi hamda minimallashtirishi kerak bo'lgan maqsad funksiyasi bilan farq qiladi. MPC qanchalik yaxshi ishlashi asosan jarayon modelining aniqligiga bog'liq. Jarayon-model nomutanosibliqi qanchalik kamaysa, uning samaradorligi shuncha ortib boradi. Taxminiy model iloji boricha sodda bo'lishi va kelajakdagi chiqish qiymatlarni ma'lum bir aniqlik bilan bashorat qila olishi kerak. Issiqxona iqlimini boshqarish uchun MPC dan foydalanish tizimga oldini olib bo'ladigan kattalikdagi har qanday og'ishlarni sodir bo'lishidan oldin javob qaytara olish qobiliyatini ta'minlaydi, bu esa tizim javobining kechikishini oldini oladi [3].

U har bir qadamda optimal boshqaruv trayektoriyasini ishlab chiqish orqali issiqxona mikroiklimini muvaffaqiyatli boshqaradi. MPC ko'p kirishli va ko'p chiqishli tizimlarda cheklovlarni hisobga olgan holda yuqori samaradorlikni ta'minlashi sababli issiqxona iqlimini optimallashtirish uchun samarali hisoblanadi. Shu bilan birga, MPC tizimdagi cheklovlarni va nohiziq bog'lanishlarni oqilona hal qiladi. Ammo, ob-havo kabi noaniq buzilishlarni bashorat qilish qiyin vazifa bo'lib qolmoqda. Muammolarni belgilash va boshqaruv maqsadlarini aniqlash usuli sababli, MPC ni ishlab chiqish va joriy etish odatda nisbatan kichik modellarni talab qiladi va statik boshqaruvga asoslangan modellarga asoslangan barqaror tizimlarda yaxshiroq ishlaydi [4,5].

MPC dan farqli ravishda, RL modelsiz boshqaruv metodologiyasi bo'lib, unda boshqaruv siyosati tizimda kuzatilgan ma'lumotlardan o'rganiladi. RL oldingi va real vaqtdagi ma'lumotlardan o'rganilgan yangi shakllantirilgan bilimni qo'shish yordamida hozirgi boshqaruv siyosatini avtomatik yangilay oladigan dinamik boshqaruv strategiyasi hisoblanadi. O'rganishga asoslangan (learning-based) va muhit (tizim) bilan sinov-xato usulida o'zaro ta'sir tufayli, RL ning boshqaruv strategiyasi tizimning joriy dinamikasiga ko'proq moslashuvchidir. Xususan, issiqxona uchun u o'simlikning turli rivojlanish bosqichlariga yanada moslashuvchan bo'la oladi. Bundan tashqari, RL ma'lumotlardan to'liq boshqaruv strategiyalarini o'rgana oladi va har doim ham yuqori aniqlikka ega model talab etilmaydi.

RL boshqaruvchilari tabiiy ravishda noaniqliklarni hal qila oladi va hech qanday mexanizmlarsiz o'zgaruvchan sharoitlarga moslashadi, chunki ular to'g'ridan-to'g'ri haqiqiy tizim bilan o'zaro ta'sir orqali o'rganishadi. Katta uzluksiz holatlar va harakatlar fazosiga ega bo'lgan murakkab tizimlar uchun RL boshqaruv uchun funksional approksimadorlar sifatida chuqur neyron tarmoqlardan (Deep Neural Networks — DNN) foydalanadi. Biroq, RL boshqaruvchilarining ajralmas kamchiligi shundaki, cheklovlarning bajarilishi bo'yicha nazariy kafolatlarning mavjud emasligi hamda DNN funksional yaqinlashuvi sababli interpretatsiya qilish imkoniyatining cheklanganligidir. Yana bir kamchilik, cheklovlarning diskret va qisqartirilgan holat hamda boshqaruv harakatlari to'plamiga ega bo'lish zaruratidir.

Xulosa

Mazkur ishda issiqxona mikroiklimini boshqarishda MPC va RL samaradorligi tahlil qilindi. Natijalar shuni ko'rsatdiki, MPC aniq va barqaror boshqaruv usulini ta'minlasa, RL murakkab va

noaniq sharoitlarda moslashuvchan boshqaruvni taklif etadi. Ushbu farqlarga qaramasdan, MPC va RL ko‘plab umumiy xususiyatlarga egadir. Masalan, MPC ham, RL ham tashqi ta’sirlar bashoratlarini o‘zlarining boshqaruv strategiyalariga kiritishdan qat’iy nazar, bashorat qiluvchi boshqaruvchi tizimlar sifatida qabul qilish mumkin. Ushbu yondashuvlarni uyg‘unlashtirish issiqxona boshqaruv tizimlarining samaradorligini oshirish va energiya resurslaridan oqilona foydalanish imkonini beradi.

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BALKA TEBRANISH TENGLAMASI UCHUN ARALASH MASALA

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Ushbu ishda biz bir jinsli balka tebranish tenglamasi uchun aralash masalani bayon qilamiz.

Ushbu $\Omega = \{(x, t) : 0 < x < p, 0 < t < T\}$ sohada quyidagi

$$u_{tt} + u_{xxxx} = 0 \quad (1)$$

tenglamani qaraylik.

A masala. Ω sohada (1) tenglamaning

$$u(x, 0) = \varphi_1(x) \quad u_t(x, 0) = \varphi_2(x) \quad (2)$$

boshlang‘ich hamda

$$u(0, t) = 0 \quad u(p, t) = 0, \quad u_{xx}(0, t) = 0 \quad u_{xx}(p, t) = 0 \quad (3)$$

chegaraviy shartlarni qanoatlantiruvchi $u(x, t)$ funksiya topilsin, bu yerda $\varphi_i(x)$, $i=1, 2$ -berilgan funksiya.

Teorema. Agar $\varphi(x) \in C[0, 1]$; $\varphi^{(k)}(x) \in L(0, 1)$ $\{k=1, 2, 3, 4, 5\}$ bo‘lib

$$\varphi(0) = 0; \varphi(p) = 0; \begin{cases} \varphi_1(p) = \varphi_1(0) = 0 \\ \varphi_2(p) = \varphi_2(0) = 0 \end{cases}; \begin{cases} \varphi_1''(p) = \varphi_1''(0) = 0 \\ \varphi_2''(p) = \varphi_2''(0) = 0 \end{cases}; \begin{cases} \varphi_1^{IV}(p) = \varphi_1^{IV}(0) = 0 \\ \varphi_2^{IV}(p) = \varphi_2^{IV}(0) = 0 \end{cases}$$

tengliklar bajarilsa, u holda A masala yechimi mavjud va u quyidagi ko‘rinishda aniqlanadi:

$$u(x, t) = \sum_{n=1}^{\infty} \left[a_n \cos\left(\frac{\pi n}{p}\right)^2 t + b_n \sin\left(\frac{\pi n}{p}\right)^2 t \right] \sqrt{\frac{2}{p}} \sin \frac{\pi n}{p} x$$

bu yerda

$$a_n = \sqrt{\frac{2}{p}} \int_0^p \varphi_1(x) \sin \frac{\pi n}{p} x dx, \quad b_n = \sqrt{\frac{2}{p}} \lambda_n^2 \int_0^p \varphi_2(x) \sin \frac{\pi n}{p} x dx.$$

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SINGULAR QO‘ZG‘ATILGAN TENGLAMANING TURLI TARTIBLI HOSILALARI DINAMIKASINI O‘RGANISHNING YUQORI ANIQLIKLI VA SAMARALI METODI

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Singular qo‘zg‘atilgan differensial tenglamalar nazariyasi amaliy matematika va fizika-mexanikaning eng muhim sohalaridan biri hisoblanadi. Ushbu tenglamalar ichida kichik parametr $\varepsilon \rightarrow 0$ bo‘lganda yechimning keskin o‘zgarish xususiyati chegara qatlamida keskin o‘zgarish paydo qiladi. Aynan shu hodisa tufayli an’anaviy sonli metodlar ko‘pincha past aniqlik bilan ishlaydi va yechim dinamikasini to‘g‘ri aks ettira olmaydi.

[1]-maqolada $\varepsilon = 10^{-2}$ va 10^{-3} da chegara qatlamida yechim va uning hosilalari qanchalik tez o‘zgarishini dastlab integrallash metodi orqali yuqori aniqlikda hisoblash jarayoni ko‘rsatiladi va ε kichraygan sari to‘g‘ri natija olish uchun N ni oshirish kerak bo‘ladi. [2]-maqolada qatlamli tuzilmalar bo‘yicha so‘nggi yutuqlar tanqidiy tahlil qilinib, natijalar umumlashtirilgan. Unda hozirgacha aniqlangan qatlam turlari, ayniqsa, eksponensial bo‘lmagan qatlamlarga alohida e‘tibor qaratilgan holda tavsiflanadi. Shuningdek, bunday qatlamlar yuzaga keladigan model masalalar va shartlar keltiriladi, qatlamlarni ajratib ko‘rsatishga mo‘ljallangan koordinata o‘zgarishlarini yaratish usullari hamda qatlamlarni aniqlash uchun to‘rlar (qatlam) tuzish yondashuvlari bayon etiladi. Bundan tashqari, ayrim model masalalarni yechish usullari ko‘rib chiqilib, ushbu metodlarning amaliy qatlamli muammolarni sonli tahlil qilishdagi qo‘llanilish imkoniyatlari muhokama qilinadi.

Spektral va spektral-to‘r metodlarida yechim Chebishev ko‘phadlari qatori ko‘rinishida yoziladi, so‘ngra differensiallanadi. Differensiallash natijasida qator hadlarining tartibi kamayadi va bu hisoblash aniqligiga salbiy ta’sir ko‘rsatadi.

Dastlab integrallash metodida esa aksincha - yechimning o‘zi emas, balki eng yuqori tartibli hosila Chebishev birinchi turdagi $T_i(y)$ ko‘phadlari qatori ko‘rinishida ifodalanadi:

Quyidagi singular qo‘zg‘algan uchinchi tartibli chegaraviy masalani qaraymiz:

$$\varepsilon u'''(y) - (d(y)u'(y))' + c(y)u'(y) + r(y)u(y) = f(y), \quad -1 < y < 1, \quad (1)$$

$$u(-1) = u(1) = u'(1) = 0. \quad (2)$$

Bu yerda $0 < \varepsilon \leq 1$ kichik parametr, $d(y), c(y), r(y), f(y)$ - berilgan funksiyalar, va quyidagi shartlar bajariladi:

$$d(y) \geq d_1 > 0,$$

$$r_0(y) = r(y) - \frac{1}{2}c'(y) \geq r_1 > 0, \quad y \in (-1, 1),$$

bu yerda d_1 va r_1 — musbat konstantalar. (1)-masalani qaraymiz, bunda:

$$d(x) = c(x) = r(x) = 1.$$

Quyidagi funktsiyani kiritamiz:

$$g(\varepsilon) = \varepsilon e^{-1/\varepsilon}.$$

$f(x)$ funktsiyani quyidagi ko‘rinishda tanlab olamiz:

$$u(x) = -g(\varepsilon) + (1 - 2\varepsilon + 2g(\varepsilon))x + (\varepsilon - g(\varepsilon) - 1)x^2 + x(1 - x)^2 + g(\varepsilon)e^{x/\varepsilon}.$$

Yuqori tartibli hosilani dastlab integrallash usulida (1)- (2) differensial masalasining yuqori tartibli hosilasi va o'ng tomoni quyidagi ko'rinishida izlanadi:

$$\frac{d^3 u}{dy^3} = u^{(3)}(y) = \sum_{i=0}^N a_i T_i(y), \quad f(y) = \sum_{i=0}^N b_i T_i(y), \quad (3)$$

(1)- (2) masalani yechilishidan oldin, uchinchi tartibli hosila uchun yozilgan (3) qator uch marta integrallanadi.

Shunday qilib, barcha quyi tartibli hosilalar va (1)–(2) masalasining yechimi Chebishev polinomlari bo'yicha chekli qatorlar ko'rinishida ifodalanadi. Shundan so'nggina, differensial tenglamada (1) mavjud bo'lgan qatorlar ushbu tenglamalarga qo'yiladi.

$$u^{(2)}(y) = \sum_{i=0}^{N+1} \sum_{j=0}^N f_{ij}^{(3)} a_j T_i + c_1 T_0,$$

$$u^{(1)}(y) = \sum_{i=0}^{N+2} \sum_{j=0}^N f_{ij}^{(2)} a_j T_i + c_1 T_1 + c_2 T_0,$$

$$u^{(0)}(y) = \sum_{i=0}^{N+3} \sum_{j=0}^N f_{ij}^{(1)} a_j T_i + \frac{c_1}{4} T_2 + c_2 T_1 + c_3 T_0,$$

Bu yerda c_1, c_2, c_3 - noma'lum o'zgaraslar bo'lib, ularni Chebishev ko'phadlarining xossaligidan foydalangan holda (2) chegaraviy shartlaridan aniqlash mumkin.

Metodning asosiy bosqichlari quyidagicha:

1. Eng yuqori hosila N ta Chebishev ko'phadlari qatori sifatida yoziladi.

2. Bu qator uch marta oldindan integrallanib, birinchi hosila va yechim uchun qatorlar hosil qilinadi.

3. Integrallashda paydo bo'lgan nomalum konstantalar c_1, c_2, c_3 chegara shartlari $u(-1) = u(+1) = 0$ dan aniqlanadi.

4. Barcha qatorlar tenglamaga qo'yilib, a_i koeffitsientlarni topish uchun chiziqli algebraik tenglamalar sistemasi (ChATS) tuziladi.

5. ChATS yechilgandan so'ng yechim va barcha tartibli hosilalar hisoblanadi.

Integrallash jarayonida Chebishev ko'phadlarining tartibi oshishi hisoblanayotgan funksiyani yanada silliqlashtiradi va bu hisoblash aniqligini sezilarli darajada yaxshilaydi. Shu bilan birga ChATS o'lchami N+1 dan oshmaydi, ya'ni arifmetik amallar soni ko'paymaydi.

Hisoblash natijalarini Chebishev ko'phadlarining aniq sonlari N, ε uchun keltiramiz. Metod $\varepsilon = 10^{-2}$ va N ning turli qiymatlarida va N = 10 dan 100 gacha bo'lgan Chebishev ko'phadlari soni uchun sinovdan o'tkazildi. Aniq yechim va uning hosilalari va taqribiy qiymatlar esa dastlab integrallash metodi orqali hisoblandi.

1-jadval. Yechimning aniq va taqribiy qiymatlari hamda uning hosilalarini taqqoslash

N	y_l	Absolyut xatoliklar			
		Yechi m	Funksiya hosilalari		
			Birinchi tartibli	Ikkinchi tartibli	Uchinchi tartibli
5 0	at 1				
	1	$1.215 \cdot 10^{-5}$	$2.441 \cdot 10^{-6}$	0.0001	0.0002
	5				
	3	$8.956 \cdot 10^{-6}$	$2.267 \cdot 10^{-5}$	$6.144 \cdot 10^{-5}$	0.00020
0	4	$1.804 \cdot 10^{-6}$	$5.258 \cdot 10^{-5}$	$1.522 \cdot 10^{-4}$	0.0156
	5				

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SHAHAR TRANSPORT TIZIMINI OPTIMALLASHTIRISHDA GRAFLAR NAZARIYASI VA EYLER SIKLLARI TADBIG'I

Qurbonmurodov Mehroj Mansur o'g'li

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Zamonaviy urbanizatsiya sharoitida shahar transport tizimini boshqarish eng murakkab logistik muammolardan biri hisoblanadi. Tirbandliklar nafaqat vaqt yo'qotilishiga, balki iqtisodiy samaradorlikning pasayishiga ham olib keladi. Ushbu maqolada transport tarmog'ini graflar nazariyasi yordamida modellashtirish va oqimlarni dinamik vazn funksiyalari orqali optimallashtirish masalalari ko'rib chiqiladi.

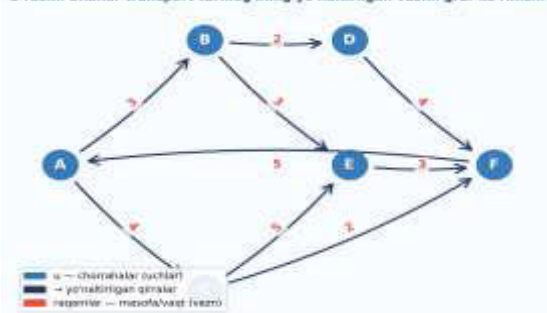
Shahar yo'l tarmoqlarini graflar nazariyasi vositasida modellashtirish

Shahar transport tizimini matematik modellashtirishda graflar nazariyasi eng samarali apparat hisoblanadi. Transport infratuzilmasini diskret matematik ob'ekt — graf ko'rinishida ifodalash zarur bo'ladi.

Modelimizda transport tarmog'i $G = (U, V)$ ko'rinishidagi yo'naltirilgan va vaznli graf sifatida aniqlanadi:

1. $U = \{u_1, u_2, \dots, u_n\}$ — Uchlar to'plami: Har bir u_i uch shahar yo'l tarmog'idagi strategik nuqtalarni (chorrahalar, aylanma yo'llar, transport tugunlari) anglatadi.
2. $V \subseteq U \times U$ — Qirralar to'plami: Yo'naltirilgan qirra $v_{ij} = (u_i, u_j)$ bo'lib, u_i chorrahadan u_j chorrahaga harakatlanish imkoniyatini ko'rsatadi.
3. $W(v_{ij})$ — Vazn funksiyasi: Qirraning o'tkazuvchanlik qobiliyati, masofasi yoki transport vositasining minimal o'tish vaqti.

1-ram. Shahar transport tarmog'ining yo'naltirilgan vaznli graf ko'rinishi



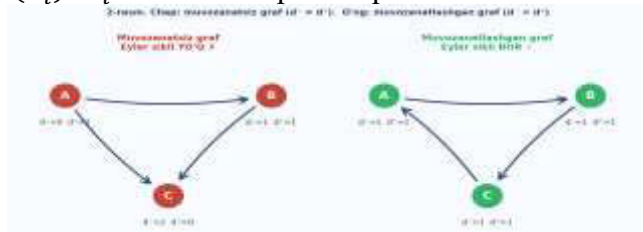
Shahar transport tarmog'ining yo'naltirilgan vaznli graf ko'rinishi. Uchlar — chorrahalar, qirralar — yo'nalishlar, raqamlar — masofa/vaqt vaznlari.

Yo'naltirilgan graflarda darajalar muvozanati

Transport tizimidagi oqimlarni matematik boshqarish uchun har bir uchda kiruvchi va chiquvchi qirralar muvozanati tahlil qilinishi shart.

Har bir $u_i \in U$ uchi uchun quyidagi tushunchalar kiritiladi:

1. Kiruvchi daraja $d^-(u_i)$: u_i uchiga kiruvchi qirralar soni.
2. Chiquvchi daraja $d^+(u_i)$: u_i uchidan chiquvchi qirralar soni.



Chap: muvozanatsiz graf — Eyler sikli mavjud emas ($d^- \neq d^+$). O'ng: muvozanatlashtirilgan graf — Eyler sikli mavjud ($d^- = d^+$).

Agar transport tarmog'ida muvozanat mavjud bo'lsa, har bir tugun uchun kiruvchi va chiquvchi yo'nalishlar darajasi graf nazariyasi qonuniyatlariga ko'ra o'zaro muvofiqlashtirilishi kerak.

Eyler sikllari va ularning yo'llarda qo'llanilishi

Maqolaning markaziy g'oyasi transport harakatini Eyler sikllari asosida tashkil etishga qaratilgan.

Eyler sikli — transport tarmog'idagi har bir yo'nalishdan takrorsiz foydalanib, boshlang'ich nuqtaga qaytuvchi marshrut bo'lib, u Eyler tipidagi yopiq siklni tashkil etadi.

Teorema (Eyler teoremasi): Yo'naltirilgan bog'langan $G = (U, V)$ grafida Eyler sikli mavjud bo'lishi uchun barcha $u_i \in U$ uchlari quyidagi shart bajarilishi zarur va yetarli:

$$d^+(u_i) = d^-(u_i), \quad \forall u_i \in U$$



Eyler siklining grafik ko'rinishi. Barcha uchlarda $d^-(u_i) = d^+(u_i)$, shuning uchun to'liq Eyler sikli mavjud.

Amaliy tatbiqi

1. Harakatni optimallashtirish: Yo'l tozalash yoki chiqindi yig'ish mashinalari har bir ko'chadan faqat bir marta o'tib, butun hududni to'liq qamrab oladi.

2. Chorrahalar muvozanati: Chorrahaga qancha yo'nalish kirsam, shuncha yo'nalish chiqishi kerak — bu transport to'planib qolishini oldini oladi.

3. Bir tomonlama yo'llarni loyihalash: Eyler grafigi shartiga keltirish orqali haydovchilarga tushunarli va uzluksiz aylanma harakat tizimi yaratiladi.

Dinamik optimallashtirish va real vaqt tahlili

An'anaviy statik modellardan farqli o'laroq, real vaqt rejimidagi transport oqimi o'zgaruvchan tabiatga ega. Grafni kengaytirilgan $G = (V, E, W(t))$ modeli sifatida ko'rib chiqamiz, bunda vazn funksiyasi vaqtga bog'liq bo'ladi.

Matematik model

Har bir qirraning t vaqt momentidagi qiymatini quyidagi dinamik funksiya orqali aniqlaymiz:

$$W(e, t) = T_{\min} \times F(\alpha)$$

$$F(\alpha) = 1 + \alpha + \alpha^2 + \alpha^3 + \alpha^4$$

Bu yerda:

1. $T_{\min}$ — yo'l bo'sh bo'lgan holatdagi minimal o'tish vaqti.
2. α — yo'lning yuklanish koeffitsiyenti ($0 \leq \alpha \leq 1$).
3. $F(\alpha)$ — yuklanish darajasiga bog'liq bo'lgan, tirbandlik ortishi bilan vaqtning chiziqli bo'lmagan o'sishini ta'minlovchi funksiya.

$F(\alpha)$ ning turli yuklanish darajalari uchun qiymatlari:

$F(\alpha)$ funksiyasining yuklanish darajasiga bog'liqligi.

α	$F(\alpha)$	Holat
0.0	1.00	Bo'sh yo'l
0.3	1.43	Qulay harakat
0.6	2.31	O'rtacha tirbandlik
0.8	3.36	Kuchli tirbandlik
1.0	5.00	To'liq to'siq

Algoritmning tatbiqi

Grafning biror qismida α koeffitsiyenti ortishi bilan $W(t)$ oshadi. Natijada, eng qisqa yo'lni hisoblovchi algoritmlar oqimni avtomatik ravishda qarshilik kamroq bo'lgan muqobil yo'nalishlarga qayta taqsimlaydi:

1. Eyler sikllari: Yo'l tozalash va kommunal xizmatlar mashinalari barcha qirralarni kamida bir marta bosib o'tishi uchun.
2. Dinamik marshrutlash: Jamoat transporti va tezkor xizmatlar uchun $F(\alpha)$ asosida eng kam vaqt sarflanadigan yo'llar tanlanadi.
3. Dijkstra algoritmi: Har bir qadamda $W(e, t)$ ning joriy qiymatiga asoslanib, eng optimal yo'l qayta hisoblanadi.

Xulosa

Ushbu tadqiqot ko'rsatdiki, shahar yo'l tarmog'ini graflar nazariyasi asosida modellashtirish transport muammolarini hal etishda muhim nazariy asos bo'la oladi. Eyler grafigi shartlarini qo'llash va dinamik vazn funksiyasini joriy etish orqali transport tizimining amaliy samaradorligini oshirish mumkinligi isbotlandi. Taklif etilgan $F(\alpha)$ dinamik vazn funksiyasi asosida qurilgan model sharoitida tirbandlik darajasini sezilarli kamaytirish mumkinligi ko'rsatildi. Kelajakda ushbu modelni real shahar ma'lumotlari bilan sinab ko'rish va natijalarni amaliyotda tekshirish maqsadga muvofiq bo'ladi.

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COMPUTER MODELING OF THE NON-STATIONARY HEAT TRANSFER PROBLEM IN AXISYMMETRIC BODIES USING THE FINITE ELEMENT METHOD

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Abstract. This article presents an algorithm for solving the non-stationary heat transfer problem in axisymmetric bodies based on the finite element method (FEM). The validity and accuracy of the developed algorithm are demonstrated through the convergence of numerical solutions as the number of finite elements increases. As a practical application, the non-stationary heat transfer process in the walls of a ceramic vessel is analyzed. Furthermore, isotherms of the computed temperature field are generated using the developed software, providing a clear visualization of the numerical results.

Key words: axisymmetric body, finite element method, cylindrical coordinate, heat conduction, boundary condition, thermal conductivity matrix.

Introduction

In many three-dimensional bodies exhibiting axial symmetry [1], the heat transfer process can be effectively reduced to an equivalent two-dimensional formulation. This transformation significantly simplifies the mathematical treatment while preserving the essential physical characteristics of the problem.

For the numerical solution of such problems [2], the finite element method is widely employed due to its flexibility in handling complex geometries. In particular, the generation of a computational mesh for irregular cross-sectional domains is more convenient within this framework. In the present study, triangular elements are adopted as the primary finite elements, as they provide greater adaptability and accuracy in approximating complex geometrical configurations.

Shape functions corresponding to linear triangular elements [3] are used in the finite element solution to the problem. They ensure its continuity at the boundary with neighboring elements since this distribution is linear along any side of the triangle and with the same change in value at the nodes, the same changes will occur along the entire inner boundary. A discrete finite element mesh model is a set of parameters that consist of the total number of finite elements and mesh nodes, arrays of their node coordinates, and node numbers of finite elements.

Some possibilities [4, 5] of solving the non-stationary heat equation in an axisymmetric multilayer medium are considered. The problem is solved by combining Fourier method and the matrix method. The solutions of the first and third boundary value problems are considered. Examples of calculations by the specified method for three-layer and five-layer axisymmetric systems are given.

In this article [6], the problem of transient heat conduction in a non-homogeneous axisymmetric body is solved using the finite element method. The cross-section of the three-dimensional axisymmetric body is discretized into a finite number of linear triangular elements. To verify the correctness of the developed algorithm and software, the transient heat conduction problem in a complex homogeneous axisymmetric body is solved.

The study addresses the problem of heat transfer in cylindrical structures [7], accounting for variations in geometry and boundary conditions. The motivation lies in the need to analyze heat propagation in engineering components with axisymmetric geometry where analytical solutions are difficult or impossible to obtain. A finite element method based on triangular mesh elements is applied to discretize the domain, and a time-dependent solution algorithm is developed using a central-difference scheme.

Formulation of the problem

The problem of non-stationary heat conduction in an axisymmetric body is investigated as a time-dependent process. The body is described in a cylindrical coordinate system (r, z) , where the temperature field is assumed to depend only on the radial coordinate r , the axial coordinate z , and time t , as follows [8]:

$$T = T(r, z, t),$$

Transient heat conduction is governed by the following heat transfer equation [10]:

$$\rho c \frac{\partial T}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left(r \lambda \frac{\partial T}{\partial r} \right) + \frac{\partial}{\partial z} \left(\lambda \frac{\partial T}{\partial z} \right) + Q(r, z, t) \quad (1)$$

where ρ - is the density of the body, c - is the specific heat capacity, λ - is the thermal conductivity coefficient, $Q(r, z, t)$ - is the internal heat source, r - is the radial distance of a point within the body from the axis of symmetry. To obtain a unique solution of the problem, appropriate initial and boundary conditions must be specified. The initial condition defines the temperature distribution of the body at time $t_0 = 0$:

$$T(r, z, 0) = T_0(r, z),$$

Boundary condition of axial symmetry ($r = 0$), meaning that no heat flux passes through the axis, which can be expressed as follows: $\frac{\partial T}{\partial r} = 0$.

On the surface of the body (S), one of the following conditions may be specified:

boundary condition of the first kind (Dirichlet condition):

$$T = T_s(r, z, t), \quad (2)$$

boundary condition of the second kind (Neumann condition):

$$-\lambda \frac{\partial T}{\partial n} = q_s, \quad (3)$$

boundary condition of the third kind (Newton condition):

$$-\lambda \frac{\partial T}{\partial n} = \alpha(T - T_\infty), \quad (4)$$

where α - heat transfer coefficient, T_∞ - ambient temperature.

In this case, the system obtained based on equation (1) and boundary conditions (2)–(4) is solved by minimizing the following functional [3]:

$$\Phi(r, z) = \int_{\Omega} \left[\frac{1}{2} r \lambda \left(\left(\frac{\partial T}{\partial r} \right)^2 + \left(\frac{\partial T}{\partial z} \right)^2 \right) - r Q T + \rho c \frac{\partial T}{\partial t} T \right] d\Omega + \int_{S_1} \frac{1}{2} q_s T dS + \int_{S_2} \frac{1}{2} \alpha (T - T_\infty)^2 dS. \quad (5)$$

where Ω - volume, S_1 - surface with a prescribed heat flux, S_2 - surface where convective heat transfer occurs.

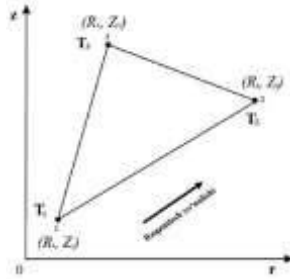


FIGURE 1. Triangular finite element

When solving the problem using the FEM, the cross-section of an axisymmetric body is divided into n finite elements. These elements are usually chosen to be triangular in shape (Figure 1). All subsequent formulations are presented specifically for triangular finite elements. The functional over the entire domain is expressed as the sum of the functionals of all finite elements. As a result, equation (5) takes the following form:

$$\Phi(r, z) = \sum_{e=1}^n \left[\frac{1}{2} \cdot \int_{\Omega^{(e)}} \{g^{(e)}\}^T \cdot [D^{(e)}] \cdot \{g^{(e)}\} d\Omega - \int_{V^{(e)}} \left(r Q^{(e)} - \rho c \frac{\partial T}{\partial t} \right) \cdot T^{(e)} dV + \int_{S_1^{(e)}} T^{(e)} \cdot q_s^{(e)} dV + \right. \\ \left. + \int_{S_2^{(e)}} \frac{1}{2} \cdot [(T^{(e)} - T_\infty)^2] \cdot \alpha^{(e)} dS \right], \quad (6)$$

where $\{g^{(e)}\}^T = \left[\frac{\partial T^{(e)}}{\partial r} \quad \frac{\partial T^{(e)}}{\partial z} \right]$, $[D^{(e)}] = \begin{bmatrix} r\lambda^{(e)} & 0 \\ 0 & r\lambda^{(e)} \end{bmatrix}$ - thermal conductivity matrix.

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RADIOTO‘LQINLARNI MUXITLAR CHEGARASIDA TARQALISH XUSUSIYATINI TADQIQ ETISH

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Annotatsiya. Mazkur tadqiqot ishida radioto‘lqinlarning turli fizik muhitlar chegaralarida tarqalish xususiyatlari nazariy va eksperimental jihatdan tadqiq etilgan. Elektromagnit to‘lqinlarning bir muhitdan ikkinchi muhitga o‘tishida yuzaga keladigan akslanish, sinish, yutilish va o‘tish hodisalari Maksvell tenglamalari asosida tahlil qilinib, laboratoriya sharoitida targetpol, kafel, gipsokarton va oyna kabi qurilish materiallarining radioto‘lqinlarni o‘tkazish xususiyatlari eksperimental ravishda o‘rganildi. Tadqiqot natijalari qurilish materiallarining fizik xossalari radioto‘lqinlarning tarqalish parametrlariga sezilarli ta‘sir ko‘rsatishini tasdiqladi. Olingan natijalar simsiz aloqa tizimlarini loyihalash va optimallashtirishda amaliy ahamiyatga ega.

Kalit so‘zlar: radioto‘lqinlar, elektromagnit to‘lqinlar, refleksiya, refraksiya, o‘tish koeffitsienti, dielektrik singdiruvchanlik, elektromagnit maydon.

Kirish

Radioto‘lqinlar elektromagnit spektrning muhim qismi bo‘lib, zamonaviy aloqa tizimlarining fizik asosini tashkil etadi. Ular radioeshittirish, mobil aloqa, radiolokatsiya, sun‘iy yo‘ldosh aloqa tizimlari va simsiz tarmoqlarda keng qo‘llaniladi. Elektromagnit to‘lqinlarning turli muhitlarda tarqalish qonuniyatlarini chuqur o‘rganish telekommunikatsiya tizimlarining samaradorligini oshirishda muhim ahamiyat kasb etadi. Ayniqsa, binolar ichida va murakkab fizik muhitlarda radioto‘lqinlarning tarqalish xususiyatlarini aniqlash simsiz aloqa sifatini yaxshilash, signal yo‘qotishlarini kamaytirish va optimal antennalar joylashuvini tanlash imkonini beradi [1,3].

Elektromagnit to‘lqinlarning fizik muhitlar chegarasida tarqalish jarayoni Maksvell tenglamalari orqali tavsiflanadi. Ushbu tenglamalar asosida ikki muhit chegarasida elektromagnit maydon komponentlarining uzluksizlik shartlari belgilanadi va natijada tushayotgan to‘lqinning bir qismi qaytishi, bir qismi esa ikkinchi muhitga o‘tishi aniqlanadi. To‘lqinning qaytish va o‘tish xususiyatlari muhitlarning dielektrik singdiruvchanligi, magnit singdiruvchanligi va elektr o‘tkazuvchanligiga bog‘liq bo‘ladi [2]. Nazariy jihatdan, agar ikki muhitning elektromagnit parametrlari keskin farq qilsa, akslanish kuchayadi, aksincha, parametrlari yaqin bo‘lsa, o‘tish koeffitsienti yuqori bo‘ladi.

Labaratoriya qurilmasi tavsifi.

Mazkur tadqiqotda radioto‘lqinlarning qurilish materiallari orqali tarqalish xususiyatlarini aniqlash maqsadida laboratoriya usuli qo‘llanildi. Tajriba 5,3–10,6 GHz chastota diapazonida ishlovchi yuqori chastotali generator yordamida amalga oshirildi. Laboratoriya qurilmasi uzatuvchi va qabul qiluvchi karnaysimon antennalar, o‘zgaruvchan attenyuator, detektorli seksiya, mikroampermetr hamda burchak o‘lchash shkalasidan tashkil topgan. Tadqiqot obyekti sifatida targetpol, kafel, gipsokarton va oyna materiallari tanlandi. Ushbu materiallar zamonaviy qurilishda keng qo‘llanilishi va simsiz aloqa tizimlarining ichki muhitda ishlashiga bevosita ta‘sir ko‘rsatishi bilan ahamiyatlidir [4].

Eksperimental tadqiqot davomida radioto‘lqinlarning materiallarga turli tushish burchaklarida yo‘naltirilishi natijasida signalning susayish darajalari o‘lchandi. Buning uchun, qaytish ko‘effitsientini o‘lchayotganda, attenyuator yordamida tushgan va o‘tgan to‘lqinlarning ko‘rsatkichlarini tenglashtirish lozim. O‘tish ko‘effitsientini o‘lchashda esa, tushgan va o‘tgan to‘lqinlarning quvvatlari nisbatini aniqlanadi va bu qiymatlarga ko‘ra, tegishli qaytish va o‘tish ko‘effitsientlari hisoblanadi. Misol uchun, qaytish ko‘effitsientining moduli qanday o‘lchanishini ko‘rib chiqaylik. Qabul qilish antenasi tushgan to‘lqin maydonida joylashtiriladi va attenyuator yordamida N1 so‘nishi kiritiladi. Unga tegishli mikroampermetr ko‘rsatkichi qayd qilinadi. Bu ko‘rsatkich taxminan 5 mkA ni tashkil etadi. So‘ng, antennani qaytgan to‘lqin maydoniga joylashtirib, attenyuator so‘nishini N2 qiymatigacha kamaytiriladi. Bunda mikroampermetr ko‘rsatkichi birinchi holatdagi qiymatni ko‘rsatishi lozim. So‘nishning o‘zgarish farqi N2–N1 detsibellarda ifodalangan yuqoridagi quvvatlar nisbatiga teng. Antenna qabul qilayotgan quvvatlar qaytgan va o‘tgan elektr maydonlarning kuchlanishlari kvadratlariga proporsional bo‘lgani uchun, quyidagi ifodani keltirib chiqarish mumkin:

$$N_2 - N_1 = 10 \lg \left| \bar{E}^- / \bar{E}^o \right|^2 = 20 \lg \left| \bar{E}^- / \bar{E}^o \right|$$

bundan

$$|R_K| = 10^{(N_2 - N_1)/20}. \quad (1)$$

Ifodasi kelib chiqadi

O‘tish ko‘effitsienti ham xuddi shu kabi o‘lchanadi. O‘tish ko‘effitsientining moduli quyidagi formula orqali hisoblanadi:

$$|\chi_K| = 10^{(N_3 - N_1)/20} \quad (2)$$

Tajriba natijalari **targetpol** materialida o‘tish ko‘effitsienti 0.901 dan 0.963 gacha o‘zgarganligini ko‘rsatdi. Bu holat targetpolning ichki strukturasi va ayrim metall komponentlari radioto‘lqinlarning qisman akslanishiga olib kelishini ko‘rsatadi. Ayniqsa, katta tushish burchaklarida signalning susayishi ko‘proq kuzatildi. Bu elektromagnit ekranlash effekti bilan izohlanadi.

Kafel materiali bo‘yicha olingan natijalar uning dielektrik xususiyatlari tufayli radioto‘lqinlarni yuqori darajada o‘tkazishini ko‘rsatdi. O‘tish ko‘effitsienti 0.95–1 oralig‘ida kuzatildi. Bu natija keramika materiallarining elektromagnit to‘lqinlar bilan o‘zaro ta‘sirida signal yo‘qotishlari minimal bo‘lishini tasdiqlaydi.

Gipsokarton materialining tadqiqot natijalari uning radioto‘lqinlar uchun eng qulay muhitlardan biri ekanligini ko‘rsatdi. O‘tish ko‘effitsienti 0.944–1 oralig‘ida bo‘lib, deyarli barcha tushish burchaklarida signalning yaxshi o‘tishi kuzatildi. Bu gipsokartonning past zichlikka ega dielektrik material ekanligi bilan izohlanadi.

Oyna materialida olib borilgan tajribalar oddiy shisha radioto‘lqinlarni yuqori darajada o‘tkazishini ko‘rsatdi (4-jadval). O‘tish ko‘effitsienti 0.95–1.017 oralig‘ida qayd etildi. Ayrim holatlarda birlikdan katta qiymatning kuzatilishi tajriba xatoligi yoki interferensiya hodisalari bilan bog‘liq bo‘lishi mumkin. Umuman olganda, oddiy shisha radioto‘lqinlarning o‘tishiga katta to‘sqinlik qilmaydi, biroq metall qoplamali oynalarda signalning sezilarli darajada susayishi mumkin.

Natijalar tahlili shuni ko‘rsatdiki, radioto‘lqinlarning tarqalish xususiyatlari nafaqat materialning turiga, balki tushish burchagiga ham bog‘liqdir. Tushish burchagi ortgan sari akslanish ko‘effitsienti ortishi va o‘tish ko‘effitsienti kamayishi kuzatiladi. Bu Maksvell tenglamalarida keltirilgan nazariy natijalar bilan mos keladi [4,5]. Shu sababli bino ichida simsiz tarmoqlarni loyihalashda devor, pol va oynalarning elektromagnit xususiyatlarini hisobga olish muhimdir.

Tadqiqot natijalariga ko‘ra, gipsokarton va oddiy oyna simsiz signal tarqalishi uchun qulay muhit hisoblanadi, targetpol va ayrim keramik materiallar esa signalning qisman yo‘qotilishiga sabab bo‘ladi. Bu natijalar Wi-Fi, mobil aloqa va boshqa simsiz tizimlarni loyihalashda amaliy

ahamiyatga ega. Ayniqsa, yopiq inshootlarda signalning optimal tarqalishini ta'minlash uchun qurilish materiallarini tanlashda ularning elektromagnit xususiyatlarini hisobga olish zarur.

Radioto'lqinlarning muhitlar chegarasida tarqalish xususiyatlarini eksperimental o'rganish elektromagnit nazariyaning amaliy tasdig'ini beradi va zamonaviy simsiz aloqa tizimlarini rivojlantirish uchun muhim ilmiy asos yaratadi. Tadqiqot natijalari kelgusida elektromagnit muhitni modellashtirish, signal yo'qotishlarini prognoz qilish va aloqa tizimlarini optimallashtirish bo'yicha ilmiy ishlanmalar uchun nazariy hamda amaliy baza bo'lib xizmat qiladi.

XULOSA

Mazkur tadqiqotda radioto'lqinlarning targetpol, kafel, gipsokarton va oddiy oyna orqali o'tish koeffitsientlari 5,3–10,6 GHz diapazonida, 0°–70° tushish burchaklari oralig'ida eksperimental ravishda o'lchandi. Asosiy xulosalar quyidagicha:

1. Gipsokarton ($T = 0,944\text{--}1,000$) va oddiy oyna ($T = 0,950\text{--}1,000$) simsiz signal tarqalishi uchun eng qulay qurilish materiallari hisoblanadi; ularning past dielektrik yo'qotish burchagi (loss tangent) signal attenüatsiyasini minimal darajada ushlab turadi.

2. Kafel ($T = 0,950\text{--}1,000$) ham yuqori o'tkazuvchanlik ko'rsatdi, ammo 20° burchakdagi anomal natija instrumenta xatoligi ekanligini tasdiqlash uchun takroriy o'lchash tavsiya etiladi.

3. Targetpol ($T = 0,901\text{--}0,963$) to'rtta material ichida eng yuqori signal yo'qotishini berdi; bu uning ichki metall komponentlari va g'ovakli tuzilmasi bilan bog'liq elektromagnit ekranlash effektidan kelib chiqadi.

4. Barcha materiallarda tushish burchagi ortishi bilan o'tish koeffitsientining kamayishi tendentsiyasi kuzatildi, bu Fresnel tenglamalarining nazariy bashoratlari bilan sifat jihatidan mos keladi.

5. Olingan natijalar Wi-Fi kirish nuqtalari, mobil aloqa atkaynorlari (repeater) va boshqa simsiz tizimlarni binolar ichida joylashtirish hamda loyihalashda amaliy ko'rsatma sifatida foydalanilishi mumkin.

Kelajakdagi tadqiqotlar uchun ushbu materiallarning dielektrik singdiruvchanligini mustaqil usul bilan aniqlash, metall qoplamali oynalar va armaturalangan betonni o'rganish, hamda turli chastotalar (2,4 GHz, 5 GHz, 28 GHz) uchun taqqoslama o'lchashlar o'tkazish tavsiya etiladi.

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ANALYSIS OF THE RESULTS OF IN-SITU LEACHING PROCESS

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Abstract

This scientific research paper presents an analysis of the results obtained based on a model and a computational algorithm representing the hydrodynamic process of In-Situ leaching, which is a method of ore extraction in natural deposits. Computational experiments made it possible to analyze in depth the influence of parameters such as permeability anisotropy of geological layers, porosity coefficient, hydrostatic gradients, initial reagent concentration and current density on the

mixing process. The pressure and concentration functions were taken into consideration as the main hydrodynamic parameters for this process to occur.

Key words: *In-Situ leaching, mathematical modeling, minerals, pressure, filtration, useful components.*

Considering the above, the article [1-2] presents a mathematical model and numerical calculation algorithm for solving problems related to pressure distribution, reagent movement, pregnant solution flow, and kinetics in an ore deposit. This article presents an analysis of the results using the ready-made [1] algorithm.

RESULTS ANALYSIS

The calculation results were performed using the Python programming language. When solving the problem, the dimensions of the sphere were taken as follows: $0 < x < 100$ (m), $0 < y < 50$ (m), z -varies depending on the ore reserve. **Fig. 1–6** show the distribution of acid in the ore-bearing plain within the mine. Production well is located in the center, and two injection wells are located at equal distances on both sides of it. Over time, the pressure increases and the dynamics of acid distribution along the medium expands. The results below reflected the spread of pressure in the medium in various situations. The results were obtained when the diameters of the productions wells were 10cm and 20cm, respectively, and the diameter of the injection well was 25cm. All results were generated within 15 days of the process.

In figure-1, graph a and graph b show the pressure distribution from the center of the sphere. Graphs c and d illustrate different views of the concentration distribution in the sphere.

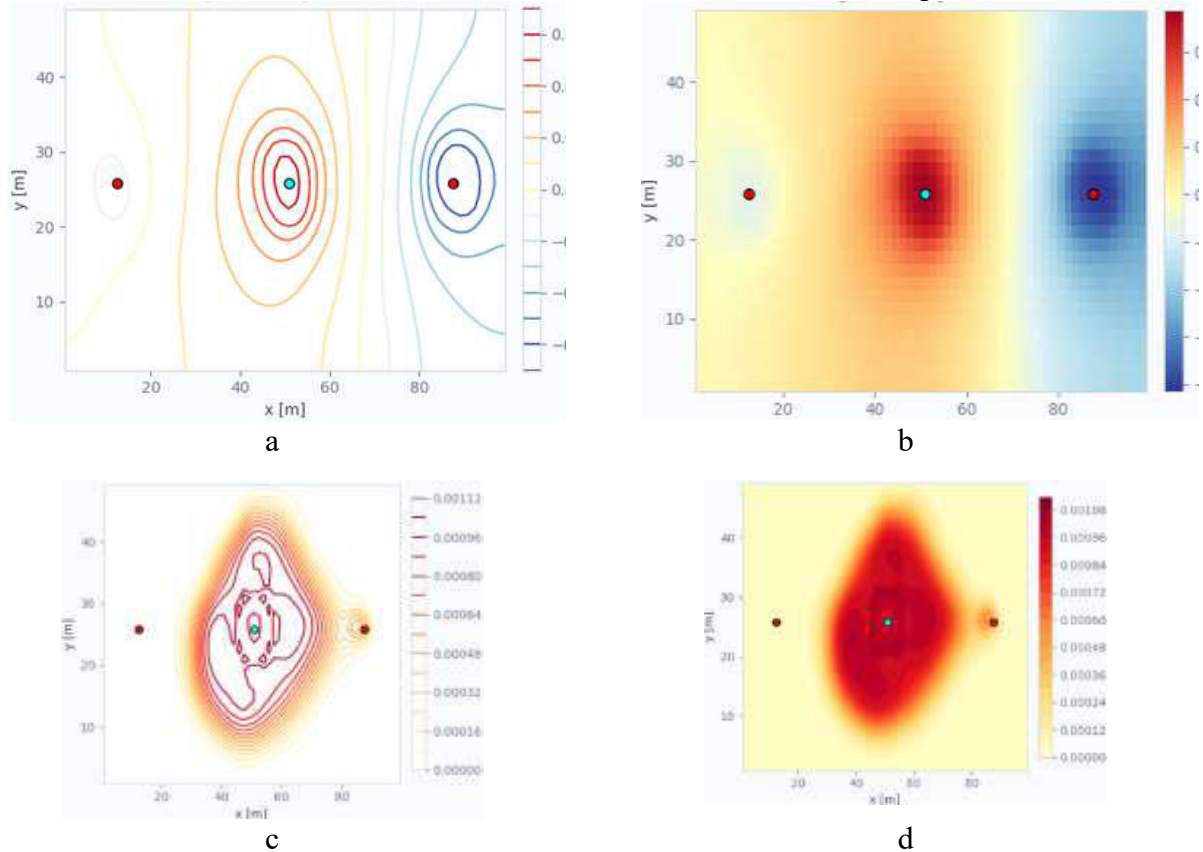


Figure-1

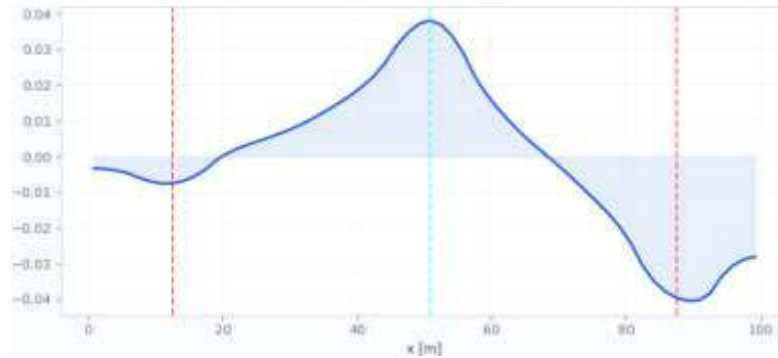


Figure-2

Figure 2 shows the variation of the pressure function with respect to the variable x . Due to the pressure distribution through the injection well, the pressure is high in the center and low around the production wells.

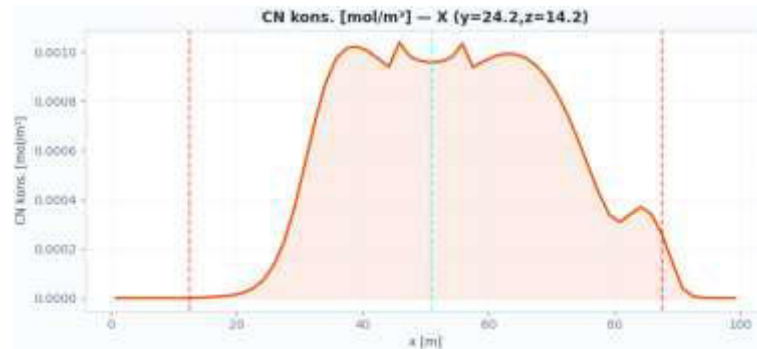


Figure-3

Figure 3 shows the variation of the concentration function with respect to the variable x . Due to the pressure distribution through the injection well, the concentration is high in the center and low around the production wells.

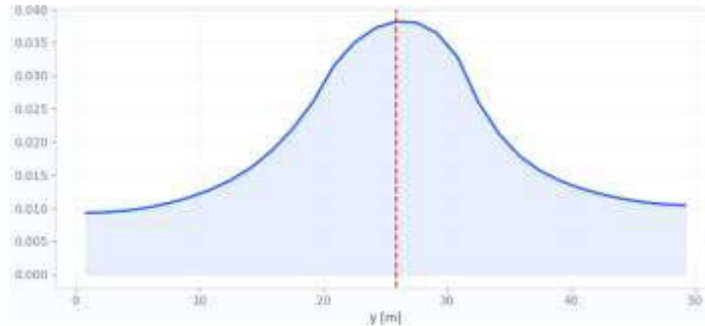


Figure-4

Figure 4 shows the variation of the pressure function with respect to the variable y . The receiving wells are not included in the image because the well locations are parallel to the Ox axis.



Figure-5

Figure 5 shows the variation of the pressure function with respect to the z variable. Since the wells are located 15 meters below the origin, the pressure reaches its highest value at this height.

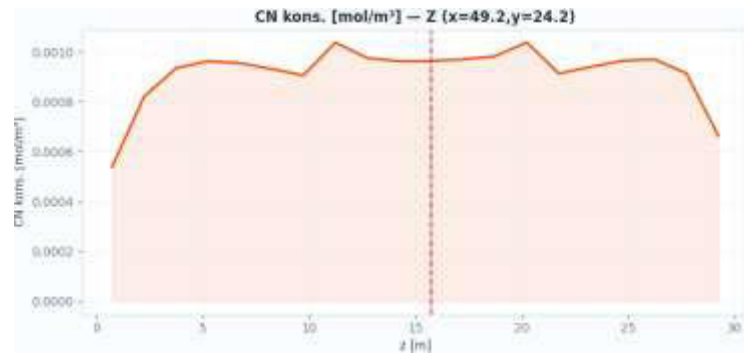


Figure-6

Figure 6 shows the variation of the concentration function with respect to the variable z .

Conclusion

The solution to this problem is carried out through the combined action of filtration, diffusion and kinetic processes. The movement of a liquid is determined by the volume or surface forces acting on it. The passage of substances in a moving liquid occurs through two completely different mechanisms. First, when there is a difference in concentrations in the liquid, molecular diffusion occurs, and secondly, a substance dissolved in a liquid is absorbed by the second during its movement. The combination of both processes is called convective diffusion of substances in a liquid. It should be noted that in the process of ISL, firstly, as a result of a change in pressure in a porous medium, and secondly, as a result of the dissolution of substance particles during acid cleaning of an ore deposit, the main hydrodynamic parameters of the object of study change.

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BLOW-UP IN DEGENERATE DIFFUSION–ABSORPTION SYSTEMS WITH TIME-DEPENDENT COUPLING

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In this paper we investigate, in the domain $Q = \{(t, x) : t > 0, x \in \mathbb{R}_+\}$ the Cauchy problem for a system of nonlinear degenerate parabolic equations with exponentially time-dependent coupling absorption terms of the form:

$$\begin{cases} \frac{\partial u}{\partial t} = \frac{\partial}{\partial x} (u^{m_1-1} \frac{\partial u}{\partial x}) - e^{\alpha_1 t} v^{k_1} \\ \frac{\partial v}{\partial t} = \frac{\partial}{\partial x} (v^{m_2-1} \frac{\partial v}{\partial x}) - e^{\alpha_2 t} u^{k_2} \end{cases} \quad (1)$$

$$\begin{cases} u(0, x) = u_0(x) \geq 0 \\ v(0, x) = v_0(x) \geq 0 \end{cases} \quad (2)$$

where $m_1 > 1, m_2 > 1, \alpha_1 > 1, \alpha_2 > 1, k_1 > 1$ and $k_2 > 1$ are given numerical parameters, and $u = u(t, x) \geq 0, v = v(t, x) \geq 0$ denote the unknown functions (solutions) of the system.

The problem (1)–(2) can be interpreted as a mathematical model describing diffusion and absorption processes of two interacting substances, species, or quantities evolving in a nonlinear medium [1], [2]. The system incorporates both self-diffusion effects and mutual interactions between the components, which are governed by nonlinear and time-dependent mechanisms [2], [3], [4]. A common and effective approach for studying solutions of such problems is based on self-similar analysis.

Below we provide a method of nonlinear splitting [1], [4] to construct self-similar equation. For construction of the self-similar solutions of the system (1) we find the solutions $u(t, x), v(t, x)$ in the form:

$$\begin{cases} u(t, x) = \bar{u}(t)w(x, \tau(t)), \\ v(t, x) = \bar{v}(t)\phi(x, \tau(t)). \end{cases} \quad (3)$$

Let $\bar{u}(t), \bar{v}(t)$ be in the form:

$$\begin{cases} \bar{u}(t) = A_1 e^{a_1(t-T)}, \\ \bar{v}(t) = A_2 e^{a_2(t-T)}, \end{cases}$$

where $A_i = (a_i a_{3-i}^{k_i})^{\frac{1}{k_1 k_2 - 1}}, a_i = \frac{k_i \alpha_{3-i} - \alpha_i}{k_1 k_2 - 1}, i = 1, 2$.

To ensure the invariance of system (1) under the self-similar transformation (3), the corresponding scaling exponents must satisfy a compatibility condition linking the nonlinear diffusion terms of both equations. In particular, the requirement that the diffusion operators retain the same homogeneity under the similarity scaling leads to the relation $(\alpha_1 + k_1 \alpha_2)(m_1 - 1) = (\alpha_2 + k_2 \alpha_1)(m_2 - 1)$.

Furthermore, balancing the amplitudes of the rescaled variables gives rise to the proportionality coefficient $l = \frac{A_2^{m_1-1}}{A_1^{m_2-1}}$, which connects the similarity constants A_1 and A_2 .

Using these compatibility conditions, one derives the parameters

$$d_1 = \frac{1}{(m_1 - 1)}, \quad d_2 = \frac{l}{(m_2 - 1)},$$

which appear in the rescaled time-dependent correction terms of the self-similar formulation [5]. Substituting the similarity representation (3) into system (1) then yields the transformed system

$$\begin{cases} \frac{\partial w}{\partial \tau} = \frac{\partial}{\partial x} \left(w^{m_1-1} \frac{\partial w}{\partial x} \right) + d_1 \tau^{-1} (\phi^{k_1} + w), \\ \frac{\partial \phi}{\partial \tau} = \frac{\partial}{\partial x} \left(\phi^{m_2-1} \frac{\partial \phi}{\partial x} \right) + d_1 l \tau^{-1} (w^{k_2} + \phi) \end{cases} \quad (4)$$

where

$$\tau(t) = \begin{cases} A_1^{m_1-1} \frac{e^{(\alpha_1 + k_1 \alpha_2)(m_1-1)t}}{(\alpha_1 + k_1 \alpha_2)(m_1-1)}, & \text{at } (\alpha_1 + k_1 \alpha_2)(m_1-1) > 0 \end{cases}$$

We consider the problem for the case $(\alpha_i + k_i \alpha_{3-i})(m_i - 1) > 0, (i = 1, 2)$

We seek the self-similar solution of system (4) in the following form:

$$w(\tau, x) = f(\xi), \quad \psi(\tau, x) = \phi(\xi), \quad \xi = \frac{x}{\tau^{\frac{1}{2}}}. \quad (5)$$

By substituting (5) into system (4), we obtain the following self-similar form:

$$\begin{cases} \frac{\partial}{\partial \xi} \left(f^{m_1-1} \frac{\partial f}{\partial \xi} \right) + \frac{\xi}{2} \frac{\partial f}{\partial \xi} + d_1 (\phi^{k_1} + f) = 0 \\ \frac{\partial}{\partial \xi} \left(\phi^{m_2-1} \frac{\partial \phi}{\partial \xi} \right) + \frac{\xi}{2} \frac{\partial \phi}{\partial \xi} + d_2 (f^{k_2} + \phi) = 0 \end{cases} \quad (6)$$

Next, the asymptotic behavior of the self-similar solutions of the system (6) is studied [7]. Self-similar solution of system equations (6) will be searched for in the form:

$$\begin{cases} f(\xi) = \bar{f}(\xi)y(\eta), & \eta = -\ln(a - \xi^2) \\ g(\xi) = \bar{g}(\xi)z(\eta) \end{cases} \quad (7)$$

where

$$\begin{cases} \bar{f}(\xi) = B_1(a - \xi^2)^{c_1}, & c_i = \frac{1}{m_i - 1}, B_i = \left(\frac{c_i + d_i}{2c_i(2c_i - 1)} \right)^{c_i}, a > 0, \\ \bar{g}(\xi) = B_2(a - \xi^2)^{c_2} \end{cases}$$

Then, substituting (7) into (6) for the function $y(\eta) > 0, z(\eta) > 0$, the following system of nonlinear equations is obtained:

$$\begin{cases} \frac{dL_1(y)}{d\eta} - a_1(\eta)L_1(y) + a_2(\eta)\frac{1}{8}\left(\frac{dy}{d\eta} - \frac{y}{m_1 - 1}\right) - a_3(\eta)z^{k_1} - a_4(\eta)y = 0 \\ \frac{dL_2(z)}{d\eta} - b_1(\eta)L_2(z) + b_2(\eta)\frac{1}{8}\left(\frac{dz}{d\eta} - \frac{z}{m_2 - 1}\right) - b_3(\eta)y^{k_2} - b_4(\eta)z = 0 \end{cases} \quad (8)$$

Here:

$$\begin{aligned} a_1(\eta) &= \frac{1}{m_1 - 1} + \frac{e^{-\eta}}{2(a - e^{-\eta})}, & a_2(\eta) &= \frac{1}{8B_1^{m_1 - 1}}, & a_3(\eta) &= \frac{d_1 B_2^{k_1}}{4B_1^{m_1}(a - e^{-\eta})^{h_1}}, & a_4(\eta) &= \frac{d_1}{4B_1^{m_1 - 1}(a - e^{-\eta})}(e^{-\eta}) \\ b_1(\eta) &= \frac{1}{m_2 - 1} + \frac{e^{-\eta}}{2(a - e^{-\eta})}, & b_2(\eta) &= \frac{1}{8B_2^{m_2 - 1}}, & b_3(\eta) &= \frac{d_2 B_1^{k_2}}{4B_2^{m_2}(a - e^{-\eta})^{h_2}}, & b_4(\eta) &= \frac{d_2}{4B_2^{m_2 - 1}(a - e^{-\eta})}(e^{-\eta}) \\ h_1 &= \frac{k_1}{m_2 - 1} - \frac{1}{m_1 - 1} + 1, & h_2 &= \frac{k_2}{m_1 - 1} - \frac{1}{m_2 - 1} + 1, \\ L_1(y) &= y^{m_1 - 1} \left(\frac{dy}{d\eta} - \frac{y}{m_1 - 1} \right), & L_2(z) &= z^{m_2 - 1} \left(\frac{dz}{d\eta} - \frac{z}{m_2 - 1} \right) \end{aligned}$$

It is supposed that $\xi \in [\xi_0, \xi_1]$, $0 < \xi_0 < \xi_1$, $\xi_1 = a^{-\frac{1}{2}}$.

Therefore, the function $\eta(\xi)$ has the properties:

$$\begin{aligned} \eta'(\xi) &> 0 \quad \text{at} \quad \xi \in [\xi_0, \xi_1], \\ \eta_0 = \eta(\xi_0) &> 0, \quad \lim_{\xi \rightarrow \xi_1} \eta(\xi) = +\infty. \end{aligned}$$

Further, we consider the solutions of the system (8), in a certain neighborhood of $+\infty$, which satisfy the inequalities

$$y_i(\eta) > 0, z_i(\eta) > 0, \quad y' - y \neq 0, \quad z' - z \neq 0.$$

Now, the asymptotic behavior of the positive solutions of (11), having a nonzero a finite limit as $\eta \rightarrow +\infty$ is studied [8].

Here, we introduce the notations:

$$c_{i1} = \frac{1}{(m_i - 1)^2}, \quad c_{i2} = \frac{1}{8B_i^{m_i - 1}(m_i - 1)}, \quad c_{i3} = \frac{d_i B_{3-i}^{k_i}}{4B_i^{m_i}}, \quad b_i = A_i B_i \quad (i = 1, 2).$$

Assume $\alpha_2(m_2 - 1) = \alpha_1(m_1 - 1)$. Then, this is validated by the following theorems:

Theorem 1. Let $h_1 > 0, h_2 > 0$. Then compactly supported solution of the problem (6), (7)

$\xi \rightarrow a^{\frac{1}{2}}$ has the following asymptotic behavior:

$$\begin{cases} f(\xi) = w_1(a - \xi^2)^{\frac{1}{m_1 - 1}}(1 + o(1)) \\ g(\xi) = w_2(a - \xi^2)^{\frac{1}{m_2 - 1}}(1 + o(1)) \end{cases} \quad (9)$$

where the coefficients $c_{i1}, i = 1, 2$ are solution of the systems of nonlinear algebraic equations

$$\begin{cases} c_{11}w_1^{m_1} + c_{12}w_1 - c_{13}w_2^{k_1} = 0, \\ c_{21}w_1^{m_2} + c_{22}w_2 - c_{23}w_1^{k_2} = 0. \end{cases} \quad (10)$$

The results obtained for problem (1)–(2) were applied within the framework of the research project funded by the Ministry of Higher Education, Science and Innovation of the Republic of Uzbekistan under the research grant AL-9224104601, titled “Mathematical modeling of processes described by nonlinear, divergent, and non-divergent parabolic equations and systems”

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NUMERICAL MODELING OF THE PROCESS OF ONEDIMENSIONAL NONLINEAR HEAT PROPAGATION

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Let us consider the following nonlinear system of cross-diffusion equations

$$\sigma_1(\chi) \frac{\partial u}{\partial t} = \operatorname{div} \left(\left| \nabla u^{l-2} \right|^{p-2} \nabla u^{l-1} \right) + \sigma_2(\chi) u^{q-1} \quad (1)$$

$$u|_{t=0} = u_0(\chi) \geq 0, \quad \chi \in \mathfrak{R}^N \quad (2)$$

where $\sigma_1(\chi) = |\chi|^m$, $\sigma_2(\chi) = |\chi|^n$, $\nabla(\cdot) = \operatorname{grad}_\chi(\cdot)$, $p > 1$, l , n , m , q are given real numbers, $N \geq 1$ is the size of the space, $u = u(t, \chi) \geq 0$ and is the desired solution.

It is known that, depending on the values of the numerical parameters, equation (1) describes various physical processes. When $n = m = 0$ equation (1) can be considered as a combustion model of a nonlinear heatconducting medium with energy release power $u^{q-1} \geq 0$ depending on temperature $u = u(\chi, t) \geq 0$, and diffusion coefficient $\mathfrak{S}(u, \nabla u) = u^{l-1} \left| \nabla u^l \right|^{p-2} \geq 0$, which is a monotonic function of the temperature gradient. In addition, equation (1) at $p = 2$ is known as the equation of a porous medium, nonlinear thermal conductivity or nonlinear diffusion [1, 7].

Below we consider the asymptotic behavior of self-similar solutions with compact support and solutions vanishing at infinity. Note that equation (1) admits in the domain $\mathbb{Q}_T$ a self-similar solution of the form

$$u = (T + t)^{-\alpha} f(\zeta), \quad \zeta = |\chi|(T + t)^{-\beta}, \quad (3)$$

Where

$$\alpha = \frac{p+n}{(q-1)(p+m)-(m-n)(l(p-1)-1)}, \quad \beta = \frac{q-l(p-1)}{(q-1)(p+m)-(m-n)(l(p-1)-1)},$$

and the function, $f(\zeta)$ in accordance with the formulation of the original problem, must satisfy the following self-similar problem

$$\zeta^{1-N} \frac{d}{d\zeta} \left(\zeta^{N-1} \left| \frac{df^{l-2}}{d\zeta} \right|^{p-2} \frac{d\zeta^{l-1}}{d\zeta} \right) + \beta \zeta^{m+1} \frac{df}{d\zeta} + \alpha \zeta^m f + \zeta^n f^{q-1} = 0, \quad (4)$$

$$f(0) = \mathbb{C} > 0, \quad f(d) = 0, \quad d < +\infty. \quad (5)$$

Theorem 1. Solution of problem (4), (5) with compact support for $\zeta \rightarrow (a/b)^{(p-1)/(p+m)}$ has an asymptotic representation

$$f(\zeta) = A \bar{f}(\zeta) (1 + o(1)),$$

where A is found from the solution of the following algebraic equation

$$\left(\frac{1}{y} \right)^{p-1} w^{l(p-1)-1} + \frac{l(b/a)^{\frac{p(1-n)+m+n}{p+m}}}{(bl(p+m))^p} w^{q-1} - \frac{\beta}{(lb(p+m))^{p-1}} = 0.$$

Case of fast diffusion ($p < 1 + 1/l$). Using the method of standard equations [1], we construct the function

$$\tilde{f}(\zeta) = \left(a + k |\zeta|^{\frac{p+m}{p-1}} \right)^{\frac{p-1}{1-l(p-1)}},$$

where $k = \frac{1-l(p-1)}{l(p+m)} \beta^{\frac{1}{p-1}}$, $a = \mathbb{C}^{\frac{l(p-1)-1}{p-1}}$, which is the upper solution to problem (4), (5), since $\Xi \tilde{f} \leq 0$.

Theorem 2. Let $-p < m < 0$, $\frac{l(N+m)+N}{l(N+m)+1} < p < 1 + 1/l$, then the solution to problem (4), (5) vanishing at infinity has the asymptotic form

$$f(\zeta) = M \tilde{f}(\zeta) (1 + o(1)),$$

where M is found from the solution of the algebraic equation

$$(1-l(p-1))^{1-p} w^{l(p-1)-1} + \frac{lb^{1-n(p-1)/(p+m)}}{(bl(p+m))^p} w^{q-1} - \frac{\beta}{(lb(p+m))^{p-1}} = 0.$$

Theorem 3. Let $q > l(p-1)$. Then the solution to problem (11), (12) with compact support has the asymptotic representation

$$g(\zeta) = C \bar{g}(\zeta) (1 + o(1)), \quad (6)$$

Where

$$C = \left(\left(\frac{l(p-1)-1}{bl(p+m)} \right)^{p-1} \beta \right)^{\frac{1}{l(p-1)-1}}, \quad \bar{g}(\zeta) = \left(D - B |\zeta|^{\frac{p+m}{p-1}} \right)^{\frac{p-1}{l(p-1)-1}}, \quad D = C^{\frac{l(p-1)-1}{p-1}}, \quad B > 0.$$

Taking into account asymptotics (6), we have the following

Corollary 1. When $l(p-1) < q < q_c = l(p-1) + \frac{p+n}{N+m}$ the unbounded solution of the Cauchy problem (1), (2) is spatially localized, and for the free boundary $x_c(t)$ there is an asymptotic behavior

$$x_c(t) \sim (D/B)^{(p-1)/(p+m)} (T-t)^\beta \rightarrow 0$$

at $t \rightarrow T^-$, i.e. spatial localization of the solution occurs.

Below are the numerical results of the problem in the form of graphs for the one-dimensional case at $l = 2.5$, $p = 3$, $q = 1.5$. The grid is broken quite finely:

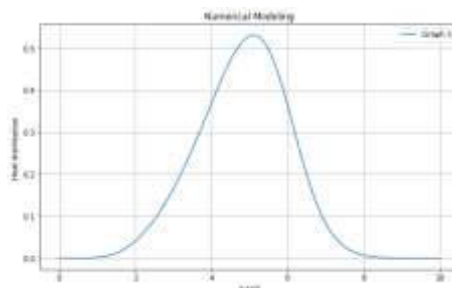


Figure 1. Heat distribution along the x-axis at time $t = 0$

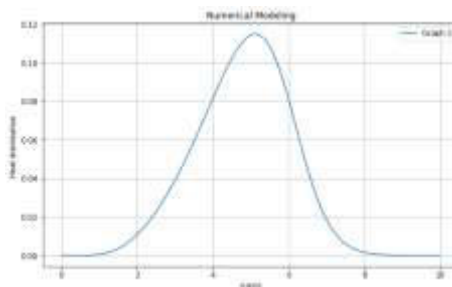


Figure 2. Heat distribution along the x-axis at time $t = 0.3$

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**COBB–DOUGLAS ISHLAB CHIQARISH FUNKSIYASINI HOSIL QILISH VA UNING
IQTISODIY MODELLASHTIRISHDAGI QO‘LLANILISHI**
Og‘abek Farmonov

Annotatsiya

Ushbu maqolada iqtisodiyotda keng qo'llaniladigan Cobb–Douglas ishlab chiqarish funksiyasining matematik hosil qilinishi ko'rib chiqiladi. Ishlab chiqarish hajmi mehnat va kapital omillariga bog'liq holda modellashdiriladi. Differensial tenglamalar yordamida ushbu funktsiyaning hosil qilinishi ko'rsatilib, uning iqtisodiy mazmuni va real iqtisodiy tizimlarda qo'llanilishi tahlil qilinadi. Tadqiqot natijalari Cobb–Douglas modelining iqtisodiy modellashdagi muhim ahamiyatini ko'rsatadi.

Kalit so'zlar: ishlab chiqarish funktsiyasi, Cobb–Douglas modeli, mehnat, kapital, iqtisodiy modellashdirish, differensial tenglamalar.

1. Kirish

1928-yilda amerikalik matematik Charles Cobb va iqtisodchi Paul Douglas Amerika iqtisodiyotining 1899–1922 yillardagi o'sishini o'rganish bo'yicha ilmiy tadqiqot e'lon qildilar. Ushbu tadqiqotda ular ishlab chiqarish hajmi mehnat va kapital miqdoriga bog'liq degan g'oyani ilgari surdilar. Iqtisodiyotda ishlab chiqarish jarayonini matematik model yordamida ifodalash muhim hisoblanadi. Shuning uchun ishlab chiqarish hajmi quyidagi funktsiya orqali ifodalanadi:

$$P = P(L, K)$$

bu yerda P — umumiy ishlab chiqarish hajmi, L — mehnat miqdori, K — kapital miqdori.

Cobb va Douglas AQSh hukumati tomonidan e'lon qilingan iqtisodiy ma'lumotlardan foydalanib statistik tahlil o'tkazdilar. Ular 1899-yilni asosiy yil sifatida tanlab, P , L va K qiymatlarini 100 ga teng deb qabul qildilar. Keyingi yillardagi qiymatlar esa foiz ko'rinishida ifodalandi. Eng kichik kvadratlar usuli yordamida ular quyidagi modelni hosil qildilar:

$$P(L, K) = 1.01L^{0.75}K^{0.25}$$

Bu model real iqtisodiy ma'lumotlarga juda yaqin natijalar bergani sababli iqtisodiyotda keng qo'llanila boshladi.

2. Chegaraviy mahsuldorlik tushunchasi

Agar ishlab chiqarish funktsiyasi

$$P = P(L, K)$$

bo'lsa, unda ishlab chiqarishning mehnat bo'yicha o'zgarish tezligi $\frac{dP}{dL}$ mehnatning chegaraviy mahsuldorligi deyiladi. Shunga o'xshash ravishda $\frac{dP}{dK}$ kapitalning chegaraviy mahsuldorligi deyiladi.

3. Cobb–Douglas funktsiyasini hosil qilish

Agar ishlab chiqarish funktsiyasi $P = P(L, K)$ deb belgilansa, unda $\frac{dP}{dL}$ ya'ni ishlab chiqarishning mehnat miqdoriga nisbatan qanday tezlikda o'zgarishi mehnatning chegaraviy mahsuldorligi deb ataladi. Shunga o'xshash ravishda $\frac{dP}{dK}$ kapitalning chegaraviy mahsuldorligi hisoblanadi. Bu yerda biz ushbu xususiy hosilalardan foydalanib Cobb va Douglas tomonidan qo'llangan modelning aynan shu shakli iqtisodiyot haqidagi quyidagi farazlardan qanday kelib chiqishini ko'rsatamiz.

(i) Agar mehnat yoki kapital yo'q bo'lsa, unda ishlab chiqarish ham yo'q bo'ladi.

(ii) Mehnatning chegaraviy mahsuldorligi har bir mehnat birligiga to'g'ri keladigan ishlab chiqarish miqdoriga $\frac{P}{L}$ ga proporsional.

(iii) Kapitalning chegaraviy mahsuldorligi har bir kapital birligiga to'g'ri keladigan ishlab chiqarish miqdoriga $\frac{P}{K}$ ga proporsional.

3.1. Faraz (ii) dan quyidagi $\frac{dP}{dL} = \alpha \frac{P}{L}$ kelib chiqadi. Bu yerda α konstanta. Agar K o'zgarmas bo'lsa $K = K_0$, unda bu xususiy differensial tenglama oddiy differensial tenglamaga aylanadi $\frac{dP}{dL} = \alpha \left(\frac{P}{L}\right)$ shu differensial tenglamani yechamiz

$$\frac{dP}{P} = \alpha \frac{dL}{L}$$

Integrallaymiz $\int \frac{dP}{P} = \int \alpha \frac{dL}{L}$, $\ln P = \alpha \ln L + C$. Bundan $P = C_1 L^\alpha$ shuning uchun $P(L, K_0) = C_1 K_0 L^\alpha$

3.2. Xuddi shunday, (iii) faraz quyidagini anglatishini ko'rsatishimiz kerak: agar L o'zgarmas bo'lsa $L = L_0$ unda $P(L_0, K) = C_2 L_0 K^\beta$ va buni yechamiz $\frac{dP}{dK} = \beta \frac{P}{K}$ agar $L = L_0$ bo'lsa $\frac{dP}{dK} = \beta \frac{P}{K}$

Ajratib olamiz: $\frac{dP}{P} = \beta \frac{dK}{K}$ va integrallaymiz: $\ln P = \beta \ln K + C$ $P = C_2 K^\beta$ shuning uchun $P(L_0, K) = C_2 L_0 K^\beta$,

3.3. 1- va 2-isbotlardan quyidagi xulosaga kelamiz: $P(L, K) = bL^\alpha K^\beta$

bu yerda b L ga ham, K ga ham bog'liq bo'lmagan konstanta. Cobb va Douglas $\alpha + \beta = 1$ deb faraz qilganlar, shuning uchun $P(L, K) = bL^\alpha K^{1-\alpha}$

3.4 Agar mehnat va kapital ikkalasi ham m marta oshirilsa $P(mL, mK) = b(mL)^\alpha (mK)^{1-\alpha} = bm^\alpha L^\alpha m^{1-\alpha} K^{1-\alpha} = bmL^\alpha K^{1-\alpha} = mP(L, K)$ Demak ishlab chiqarish m marta oshadi.

3.5. Endi quyidagini ko'rsatamiz: $P(L, K) = bL^\alpha K^{1-\alpha}$ shu tenglama quyidagi xususiy differensial tenglamani qanoatlantiradi

$$L \frac{dP}{dL} + K \frac{dP}{dK} = P$$

Yechim: $\frac{dP}{dL} = \alpha bL^{\alpha-1} K^{1-\alpha}$, $L \frac{dP}{dL} = \alpha bL^\alpha K^{1-\alpha}$, $\frac{dP}{dK} = (1-\alpha)bL^\alpha K^{-\alpha}$, $K \frac{dP}{dK} = (1-\alpha)bL^\alpha K^{1-\alpha}$, Qo'shib yuborsak: $L \frac{dP}{dL} + K \frac{dP}{dK} = \alpha bL^\alpha K^{1-\alpha} + (1-\alpha)bL^\alpha K^{1-\alpha} = bL^\alpha K^{1-\alpha} = P$

4. Amaliy hisoblash

Cobb va Douglas Amerika iqtisodiyotini 1899–1922 yillar uchun modellashtirishda quyidagi funksiyadan foydalananganlar $P(L, K) = 1.01L^{0.75}K^{0.25}$ 1920-yilda $L = 194$ va $K = 407$ bo'lganda mehnat va kapitalning chegaraviy mahsuldorligini topamiz.

Mehnatning chegaraviy mahsuldorligi: $\frac{dP}{dL} = 1.01(0.75)L^{-0.25}K^{0.25} = 0.7575L^{-0.25}K^{0.25}$

$$\frac{dP}{dL}(194, 407) \approx 0.911$$

Kapitalning chegaraviy mahsuldorligi: $\frac{dP}{dK} = 1.01(0.25)L^{0.75}K^{-0.75} = 0.2525L^{0.75}K^{-0.75}$, $\frac{dP}{dK}(194, 407) \approx 0.145$, $0.911 > 0.145$. Natijalar shuni ko'rsatadiki, o'sha davrda ishlab chiqarishni oshirish uchun mehnat resurslarini ko'paytirish kapitalni oshirishdan ko'ra samaraliroq bo'lgan.

Xulosa

Cobb–Douglas ishlab chiqarish funksiyasi iqtisodiy jarayonlarni matematik modellashtirishda muhim rol o'ynaydi. Ushbu model ishlab chiqarish hajmini mehnat va kapital orqali ifodalash imkonini beradi. Bugungi kunda ushbu model makroiqtisodiyot, iqtisodiy o'sish nazariyasi va ishlab chiqarish jarayonlarini tahlil qilishda keng qo'llanilmoqda.

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X-QUTBLANISHLI PANEL ANTENNANING KOMPYUTERDA MODELLASHTIRILISHI VA ELEKTROMAGNIT PARAMETRLARINI TAHLIL QILISH

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Annotatsiya. Ushbu maqolada televizion uzatuvchi X-qutblanishli (cross-polarized) panel antenning MMANA-GAL dasturiy muhitida kompyuterda modellashirilishi va uning asosiy elektromagnit parametrlarini tahlil qilish natijalari bayon etilgan. Momentlar usuli (Method of Moments, MoM) asosida qurilgan hisoblash modeli yordamida antenning yoʻnalganlik diagrammasi, kuchaytirish koeffitsienti, samaradorlik koʻrsatkichi, kirish impedansi va qutblanishlararo izolyatsiya parametrlari aniqlangan. Olingan natijalar X-qutblanishli tuzilmaning yon barglarni kamaytirish va interferensiyaga chidamlilikni oshirishdagi ustunligini tasdiqlaydi.

Kalit soʻzlar: panel antenna, X-qutblanish, MMANA-GAL, yoʻnalganlik diagrammasi, kuchaytirish koeffitsienti, DVB-T2, momentlar usuli.

KIRISH

Yer usti raqamli televideniye tizimlarida (DVB-T/T2 standarti) signal uzatish sifati koʻp jihatdan uzatuvchi antenna tizimlarining elektromagnit xususiyatlariga bogʻliq. Bu xususiyatlar orasida yoʻnalganlik diagrammasining shakli, kuchaytirish koeffitsienti, samaradorlik va qutblanish tozaligi alohida ahamiyat kasb etadi [1, 2].

Zamonaviy televideniye uzatish stansiyalarida kengroq qoʻllaniladigan antennalar turiga X-qutblanishli (cross-polarized) panel antennalar kiradi. Ushbu antennalar ikkita oʻzaro perpendikulyar yoʻnalishda qutblangan elektromagnit maydonni bir vaqtda hosil qilib, koʻp yoʻllilik (multipath) taʼsirini kamaytirishga va signal barqarorligini taʼminlashga xizmat qiladi [3, 4]. Murakkab shaharsozlik muhitida, togʻli relefli hududlarda va zich bino-inshootlar orasida bunday antennalarning afzalligi ayniqsa yaqqol namoyon boʻladi.

Antenna tizimlarini fizik prototip yaratmasdan avval kompyuterda modellashirish zamonaviy telekommunikatsiya muhandisligida keng qoʻllaniladigan yondashuvga aylangan [5]. Bu usul loyihalash xarajatlarini sezilarli kamaytirib, parametrlarni tezkor optimallashtirish imkonini beradi. Ushbu ishning maqsadi MMANA-GAL dasturiy muhitida X-qutblanishli panel antenning geometrik va elektromagnit modelini yaratish, asosiy ishlash parametrlarini hisoblash hamda olingan natijalarni nazariy maʼlumotlar bilan qiyosiy tahlil qilishdan iborat.

NAZARIY ASOS VA MODELLASHTIRISH USULI

X-qutblanishli panel antenning tuzilishi

X-qutblanishli panel antenna konstruktiv jihatdan ikkita bir-biriga perpendikulyar joylashtirilgan dipol juftliklaridan tashkil topadi. Har bir dipol jufti mustaqil signal kirishiga ega boʻlib, ular oʻzaro 90° fazaviy siljish bilan qoʻzgʻatiladi. Buning natijasida antenning nurlanish maydonida gorizont (H) va vertikal (V) qutblanish komponentlari parallel ishlaydi.

Panel antenna tuzilmasida nurlatgich elementlar odatda aks ettiruvchi ekran (reflektor) oldida yarim toʻlqin uzunligiga ($\lambda/2$) teng masofada joylashtiriladi. Elementlar orasidagi masofa va ularning fazaviy moslashuvi antenning yoʻnaltirilganlik diagrammasini shakllantirishning asosiy omillari hisoblanadi. Koʻp elementli panjarali tuzilmada individual elementlarning interferensiyasi hisobiga asosiy nurlanish yoʻnalishida amplitudaviy maksimum hosil boʻladi va yon barglar darajasi kamayadi.

Momentlar usuli

MMANA-GAL dasturi antenning elektromagnit xususiyatlarini Momentlar usuli asosida hisoblaydi [6]. Ushbu usul Harrington tomonidan ishlab chiqilgan boʻlib, u Fredholm integral tenglamasini diskretlashtirish orqali antenna simi boʻylab tok taqsimotini aniqlashga asoslanadi. Matematik jihatdan muammo quyidagi integral tenglamani yechishga keltiriladi:

$$E^i(r) = \int Z(r, r') \cdot J(r') dl' \quad (1)$$

bu yerda $E^i(r)$ — taʼsir etuvchi elektr maydon, $Z(r, r')$ — impedans yadro funksiyasi, $J(r')$ — simning yuzasi boʻylab tok zichligi. MoM yordamida lineer algebraik tenglamalar sistemasiga oʻtib, tok taqsimoti va undan kelib chiquvchi barcha elektromagnit kattaliklar aniqlanadi.

Hisoblash modeli

Modellashtirish uchun DVB-T2 standartiga mos keluvchi 690 MHz markaziy chastotasi (UHF IV-V diapazon) tanlandi. Antenning geometrik parametrlari quyidagicha belgilandi: yarim toʻlqinli dipol elementi uzunligi $l = \lambda/2 \approx 217$ mm, element diametri $d = 10$ mm, reflektor ekrani

o'lchami 400×400 mm, element-reflektor orasidagi masofa $h = \lambda/4 \approx 108$ mm. To'rt elementli lineal panjara (4×1 array) uchun elementlar orasidagi masofa $d_a = \lambda/2 = 217$ mm qilib olindi.

MMANA-GAL muhitida antenna modeli segmentlarga bo'lingan simlar to'plami sifatida ifodalandi. Har bir segment uzunligi $\lambda/20$ dan oshmasligi va minimal segmentlar soni 10 ta bo'lishi shartlari bajarildi. Hisoblashlar 300 ta segment va 150 ta noma'lum tokli nuqtalar yordamida amalga oshirildi.

MODELLASHTIRISH NATIJALARI VA MUHOKAMA

Yo'nalganlik diagrammasi

Modellashtirish natijasida 690 MHz chastotada X-qutblanishli panel antenning uch o'lchamli yo'nalganlik diagrammasi (3D radiation pattern) va uning asosiy kesimlar bo'yicha proyeksiyalari olindi. Gorizontol kesim (azimut tekisligi, H-tekislik) bo'yicha asosiy barg kengligi -3 dB sathda 65° ni tashkil etdi, bu esa ko'p sektorli antenna tizimlarida qo'llash uchun optimal hisoblanadi.

Vertikal kesim (elevatsiya tekisligi, E-tekislik) bo'yicha asosiy nurlanish barg kengligi 14° ga teng bo'ldi, bu esa katta masofaga yo'naltirilgan uzatishda energiyaning samarali jamlanishini ta'minlaydi. Yon barglarning maksimal darajasi asosiy bargga nisbatan -18 dB ni tashkil etib, DVB-T2 standarti talablarini qanoatlantiradi [2].

Kuchaytirish koeffitsienti va samaradorlik

To'liq ishlash diapazoni (680–700 MHz) bo'ylab olingan hisoblash natijalari shuni ko'rsatdiki, 690 MHz da maksimal yo'naltirilgan kuchaytirish koeffitsienti $D = 11,4$ dBi, antenning umumiy kuchaytirish koeffitsienti esa $G = 10,8$ dBi ga teng. Samaradorlik ko'rsatkichi $\eta = 85,3\%$ ni tashkil etdi, bu esa konstruktivdagi yo'qotishlar $0,65$ dB dan oshmasligini bildiradi.

Kirish impedansi $Z_{in} = (47,3 + j3,8)$ Om bo'lib, 50 Om standart uzatish liniyasi bilan mos kelish koeffitsienti $VSWR = 1,18$ ga teng bo'ldi. Aks etish yo'qotishi $S_{11} = -20,4$ dB qiymat, ya'ni kiruvchi quvvatning $99,1\%$ antennga uzatilib, atigi $0,9\%$ aks etishi aniqlanadi.

Qutblanishlararo izolyatsiya

X-qutblanishli antenning muhim parametrlaridan biri — gorizontol va vertikal qutblanish portlari orasidagi izolyatsiya darajasi (cross-polarization discrimination, XPD). Modellashtirish natijasida asosiy nurlanish yo'nalishida $XPD = 32$ dB qiymat olindi, bu esa ikki qutblanishning bir-biriga ta'sirini minimum darajaga tushirishini anglatadi. Ushbu ko'rsatkich 3GPP va ITU-R standartlarida tavsiya etilgan 25 dB minimal qiymatdan yuqori hisoblanadi [4].

Portlar orasidagi izolyatsiya $S_{21} = -35,6$ dB ni tashkil etdi. Bu natija antenning ikki mustaqil qutblanish kanali orqali bir vaqtda ishlashiga imkon beradi va MIMO (Multiple Input Multiple Output) texnologiyasi talablarini qondiradi.

Chastota xususiyatlari

Antenning ish diapazonidagi xususiyatlari tekshirilganda, -10 dB sathda impedans kengligi 62 MHz ni (661 – 723 MHz) tashkil etishi aniqlandi. Bu ko'rsatkich DVB-T2 standarti talabini (8 MHz kanal kengligi) sezilarli darajada qondiradi va antenning keng polosali ekanligini ko'rsatadi. Kuchaytirish koeffitsienti shu diapazonda $\pm 0,3$ dB chegarasida deyarli tekis bo'lib qoladi.

XULOSA

Ushbu ishda MMANA-GAL dasturiy muhitida X-qutblanishli panel antenning to'liq elektromagnit modeli yaratildi va asosiy ishlash parametrlari Momentlar usuli yordamida aniqlandi. Olingan natijalar quyidagi xulosalarga olib keladi:

1. 690 MHz chastotada antenning yo'naltirilgan kuchaytirish koeffitsienti $G = 10,8$ dBi bo'lib, DVB-T2 uzatish tizimlarida talab qilinadigan minimal 8 dBi qiymatdan yuqori hisoblanadi.

2. Qutblanishlararo izolyatsiya $XPD = 32$ dB qiymat, $S_{21} = -35,6$ dB ko'rsatkichi antenning MIMO va ko'p qutblanishli uzatish texnologiyalarida samarali qo'llanilishi mumkinligini tasdiqlaydi.

3. Antenning samaradorligi $\eta = 85,3\%$, aks etish yo'qotishi $S_{11} = -20,4$ dB va $VSWR = 1,18$ qiymatlari yaxshi impedans mosligini ko'rsatadi.

4. MMANA-GAL dasturi yordamida amalga oshirilgan kompyuter modellashtirish usuli antenna tizimlarini fizik prototip yaratmasdan avval samarali loyihalash imkonini beradi va vaqt hamda moddiy xarajatlarni sezilarli kamaytiradi.

Kelgusida ushbu tadqiqot asosida ko'p elementli fazali antenna panjarasini ishlab chiqish, chastota diapazonini kengaytirish va real mahalliy relyef sharoitlarida uzatish modellarini tahlil qilish maqsadga muvofiq hisoblanadi.

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MATHEMATICAL MODEL OF FOULING PROCESS AND TRANSPORT PROBLEM IN CYLINDRICAL POROUS MEDIA

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Abstract. This work addresses the development of a mathematical model for water filtration processes in a cylindrical porous medium. The mathematical model allows for the evaluation of the water filter's operational efficiency by taking into account changes in concentration, porosity, pressure, and the fouling process. A mathematical model and a numerical algorithm describing a system of partial differential equations and their corresponding initial and boundary conditions were developed to solve the problem. Computer simulations were conducted using software developed for the process under consideration. Using the proposed mathematical model, it is possible to predict the concentration change in a cylindrical porous medium over a required time interval, taking into account a number of factors.

Analysis of filtration and mass conservation processes in porous media is an important issue for the mechanical and chemical purification and recycling of fluids in industrial and environmental sectors. The movement of the fluid, based on its physical properties, directly influences flow dynamics and mass exchange processes. For cylindrical porous filters, flow is typically described by the Darcy or Brinkman–Darcy equations. The mass conservation equation for liquid concentration describes the movement, distribution, and loss of particles within the filter. The main processes are advection, diffusion, and fouling, which together fully characterize the motion of particles in the liquid.

In [1–2], the motion of an incompressible fluid is examined, and the free-stream regions are expressed in terms of the Navier–Stokes equations. In the integrated mathematical model of the radial filtration process in a cylindrical filter, the flow is directed from the outer annulus into the inner cavity. Filtration through the porous layer is described by Darcy's law, and the pressure distribution is represented by Poisson's equation. The transport of dissolved substances is modeled using an advection-diffusion equation. In the study, taking into account the vertical orientation of

the cylindrical filter had a significant effect on reducing energy consumption and increasing process efficiency.

Mass conservation equation for a cylindrical porous medium, taking into account the flow and medium balance:

$$\frac{\partial \phi}{\partial t} + \frac{1}{r} \frac{\partial(r \cdot v_r)}{\partial r} + \frac{1}{r} \frac{\partial v_\theta}{\partial \theta} + \frac{\partial v_z}{\partial z} = 0.$$

The mass conservation equation does not fully represent the filtration process; this equation expresses the direct interaction between the medium and the flow, and between the flow and the medium. To fully represent the process, Darcy's flow equations and the mass conservation equations for concentration are also used. In a porous medium, fluid flow occurs under the influence of pressure gradients and gravitational forces. The flow rate is directly proportional to the medium's permeability and inversely proportional to its viscosity:

$$v = -\frac{k}{\mu}(\nabla p + \rho g \nabla z).$$

Changes in the concentration of particles in a fluid occur as a result of advection (transport by flow), diffusion (spread due to a concentration gradient), and fouling (deposition):

$$\begin{aligned} \frac{\partial(\phi C)}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r}(r \cdot v_r \cdot C) + \frac{1}{r} \frac{\partial}{\partial \theta}(v_\theta \cdot C) + \frac{\partial}{\partial z}(v_z \cdot C) = \\ = D_{eff} \left[\frac{1}{r} \frac{\partial}{\partial r}(r \frac{\partial C}{\partial r}) + \frac{1}{r^2} \frac{\partial^2 C}{\partial \theta^2} + \frac{\partial^2 C}{\partial z^2} \right] - R_f. \end{aligned}$$

The effective diffusion coefficient was taken to express the process more precisely:

$$D_{eff} = \frac{D_m}{\tau} + \alpha_L |v|, \quad |v| = \sqrt{v_r^2 + v_\theta^2 + v_z^2}.$$

In a porous medium, the actual distribution of particles is not limited to molecular diffusion alone. To account for flow heterogeneity, mechanical dispersion arising from channel tortuosity, and gravitational effects, an effective diffusion coefficient was applied in the model.

During the filtration process, particles adhere to the pore walls and accumulate on the filter surface, resulting in a reduction of porosity and the buildup of substances on the filter surface. The fouling process is characterized by the accumulation of solid particles in the porous medium or on filter surfaces, leading to reduced porosity, increased hydraulic resistance, and decreased filter efficiency. The following equation expresses the evolution of the sediment concentration:

$$R_f = \frac{\partial \sigma}{\partial t} = k_{dep} C |v| - k_{ero} \sigma |v|.$$

Porosity changes as a result of particle adhesion to the pore wall and the accumulation of sedimentary rocks:

$$\phi = \phi_0 - \frac{\sigma}{\rho_s},$$

The porosity change equation describes the reduction in void volume resulting from sediment accumulation within the filter. This equation is directly linked to fouling kinetics and enables determination of the time-dependent changes in the filter's hydraulic properties:

$$\frac{\partial \phi}{\partial t} = -\frac{1}{\rho_s} \frac{\partial \sigma}{\partial t} = -\frac{R_f}{\rho_s}.$$

The dependence of permeability on porosity is expressed through a simplified power-law, and this approach is considered an empirical approximation of the Kozeny–Karman relationship. This equation accounts for the narrowing of flow channel cross-sections and the increase in hydraulic resistance that result from fouling-induced porosity reduction. Here, the coefficient β characterizes the filter's sensitivity to the fouling process.

$$k = k_0 \left(\frac{\phi}{\phi_0} \right)^\beta,$$

The time-dependent variation of conductivity is as follows:

$$\frac{\partial k}{\partial t} = k_0 \cdot \beta \cdot \left(\frac{\phi}{\phi_0}\right)^{\beta-1} \cdot \frac{1}{\phi_0} \cdot \frac{\partial \phi}{\partial t}.$$

The cylindrical filter is characterized by the following geometric parameters:

$$\Omega = \{(r, \theta, z) : 0 \leq r \leq R, 0 \leq \theta < 2\pi, 0 \leq z \leq H\}$$

The initial conditions (in the case $t=0$):

$$C(r, \theta, z, 0) = 0, \quad \sigma(r, \theta, z, 0) = 0, \quad \phi(r, \theta, z, 0) = \phi_0,$$

$$k(r, \theta, z, 0) = k_0, \quad p(r, \theta, z, 0) = p_0(z), \quad p_0(z) = p_{atm} + \rho g(H - z).$$

Boundary conditions:

Entrance ($z=0$, from top) boundary conditions

$$C(r, \theta, 0, t) = C_{in}(t), \quad v_z(r, \theta, 0, t) = v_{in}(t).$$

Exit ($z=H$, from bellow) boundary conditions

$$\left. \frac{\partial C}{\partial z} \right|_{z=H} = 0, \quad p(r, \theta, H, t) = p_{atm}.$$

Boundary conditions for the axis of symmetry ($r=0$)

$$\left. \frac{\partial C}{\partial r} \right|_{r=0} = 0, \quad \left. \frac{\partial p}{\partial r} \right|_{r=0} = 0, \quad v_r(0, \theta, z, t) = 0.$$

Boundary conditions of the side wall ($r=R$)

$$v_r(R, \theta, z, t) = 0, \quad \left. \frac{\partial C}{\partial r} \right|_{r=R} = 0, \quad p(R, \theta, z, t) = p_{ext}(z, t), \quad C(R, \theta, z, t) = 0.$$

Angle periodicity condition

$$C(r, 0, z, t) = C(r, 2\pi, z, t), \quad \left. \frac{\partial C}{\partial \theta} \right|_{\theta=0} = \left. \frac{\partial C}{\partial \theta} \right|_{\theta=2\pi}, \quad p(r, 0, z, t) = p(r, 2\pi, z, t).$$

The mathematical model developed for the pressureless filtration processes presented in this work cannot, in general, be solved analytically. The main reason is the complexity, strong interdependence, and nonlinear nature of the model's system of equations. The main equations used in the model—Darcy's law, the mass conservation equation for suspended particles, and fouling kinetics—are coupled in a nonlinear fashion. For this reason, numerical methods were used to solve the above system of equations. The finite difference method was employed for discretization, and the computations were carried out on a computer.

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HAR QANDAY TUB SONNING $6k + 1$ YOKI $6k - 1$ KO'RINISHIDA IFODALANISHI HAQIDA

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Annotatsiya. Ushbu tezida 3 dan katta bo'lgan har qanday tub sonning $6k + 1$ yoki $6k - 1$ (bu yerda k natural son) ko'rinishida yozilishi mumkinligi isbotlanadi. Barcha butun sonlar 6 ga bo'lishda qoldiq bo'yicha sinflarga ajratiladi. Tub sonlar 2 va 3 dan tashqari, 6 ga bo'linmaydi.

Shuning uchun ularning qoldig'i faqat 1 yoki 5 bo'lishi mumkin, bu esa $6k + 1$ va $6k - 1$ ko'rinishlariga ekvivalentdir. Isbot elementar sonlar nazariyasiga asoslangan va hech qanday murakkab apparatni talab qilmaydi.

Kalit so'zlar. tub sonlar, $6k \pm 1$ ko'rinishi, qoldiq sinflari, sonlar nazariyasi, elementar isbot

Kirish. Tub sonlar — bu faqat 1 va o'ziga bo'linadigan 1 dan katta natural sonlar. Ular matematikaning asosiy tushunchalaridan biri hisoblanadi. Ko'p hollarda tub sonlarni qulay analitik ko'rinishda ifodalash ularning xossalari o'rganishni osonlashtiradi.

Ma'lumki, barcha juft sonlar 2 dan tashqari tub emas. Shuningdek, 3 ga bo'linadigan sonlar faqat 3 ning o'zi tub bo'lishi mumkin. Shu sababli, 2 va 3 dan katta bo'lgan tub sonlar 2 ga ham, 3 ga ham bo'linmaydi. Ushbu tezisda aynan shu kuzatish asosida $6k + 1$ va $6k - 1$ ko'rinishlarining yagona mumkin bo'lgan shakllar ekanligi ko'rsatiladi.

1. Butun sonlarni 6 ga bo'lishdagi qoldiqlar

Har qanday butun son n ni 6 ga bo'lganda, qoldiq quyidagi 6 ta qiymatdan biriga ega bo'lishi mumkin:

$$n = 6q + r, \quad r \in \{0, 1, 2, 3, 4, 5\}$$

Bu yerda q — butun son (manfiy bo'lishi ham mumkin, lekin natural sonlar uchun $q \geq 0$).

Tub sonlar uchun mumkin bo'lgan qoldiqlar

Faraz qilaylik, $p > 3$ tub son bo'lsin. U holda:

1. Agar $r = 0$ bo'lsa, $p = 6q \Rightarrow 6$ ga bo'linadi $\Rightarrow$ tub emas (6 tub emas).

2. Agar $r = 2$ bo'lsa, $p = 6q + 2 = 2(3q + 1) \Rightarrow 2$ ga bo'linadi va $p > 2 \Rightarrow$ tub emas.

3. Agar $r = 3$ bo'lsa, $p = 6q + 3 = 3(2q + 1) \Rightarrow 3$ ga bo'linadi va $p > 3 \Rightarrow$ tub emas.

4. Agar $r = 4$ bo'lsa, $p = 6q + 4 = 2(3q + 2) \Rightarrow 2$ ga bo'linadi $\Rightarrow$ tub emas.

Shunday qilib, faqat $r = 1$ va $r = 5$ qoldiqlari qoladi.

$6k + 1$ va $6k - 1$ ko'rinishlari

Agar $r = 1$: $p = 6q + 1$. Bu yerda $k = q$ deb olsak, $p = 6k + 1$.

Agar $r = 5$: $p = 6q + 5 = 6(q + 1) - 1$. Agar $k = q + 1$ desak, $p = 6k - 1$.

Demak, 3 dan katta har qanday tub son albatta $6k + 1$ yoki $6k - 1$ ko'rinishida yoziladi.

Teskari to'g'ri emasligi

Shuni alohida ta'kidlash kerakki, $6k + 1$ yoki $6k - 1$ ko'rinishidagi har bir son tub bo'lavermaydi. Masalan:

6. $k = 4$: $6 \cdot 4 - 1 = 23$ (tub), $6 \cdot 4 + 1 = 25$ (tub emas).

7. $k = 6$: $6 \cdot 6 - 1 = 35$ (tub emas).

Bu shart **zaruriy** shart, ammo **yetarli** emas.

Xulosa

Ushbu tezisda quyidagi natijalar ko'rsatildi:

1.2 va 3 dan farqli barcha tub sonlar 6 ga bo'lganda qoldiq faqat 1 yoki 5 bo'lishi mumkin.

2. Qoldiq 1 bo'lgan sonlar $6k + 1$ ko'rinishida, qoldiq 5 bo'lgan sonlar esa $6k - 1$ ko'rinishida ifodalanadi.

3. Bu ifodalash zaruriy shart bo'lib, barcha tub sonlar (2 va 3 dan tashqari) shu ikki sinfga ajraladi.

4. Biroq bu sinflarning har bir elementi tub emas — qarama-qarshi misollar mavjud.

Ushbu natija tub sonlarni qidirish, ularni tekshirish va sinflarga ajratishda asosiy vosita sifatida xizmat qilishi mumkin.

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ЗАДАЧА ФИЛЬТРАЦИИ ФЛЮИДОВ В НЕСВЯЗАННЫХ ТРЕХСЛОЙНЫХ ПЛАСТАХ.

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Аннотация. Работа посвящена к построение математической модели задачи фильтрации нелинейных флюидов гидро динамически несвязанных трехслойных пластах при совместной эксплуатации. Численные алгоритмы решения, построена с применением метода итерации, метода прямых и разностного варианта метода потоковой прогонки

Процесс фильтрации различных флюидов в подземных пористых средах, представляет значительный интерес, особенно в тех случаях когда коэффициенты пласта и флюида изменяется экспоненциально и зависят от градиента давления и от пьезометрических характеристик пласта. При фильтрации таких флюидов подвижные границы тоже зависят от экспоненциальных пластовых параметров флюида и среды влияющие на продвижение границы различных зон процесса фильтрации. При фильтрации структурированных флюидов между зонами ползучести, аномальной подвижности и областями ускоренных подвижностей на неизвестных границах между этими зонами [1-3] предполагается сохраненные непрерывности давления и скорости фильтрации.

Экспоненциальные математические модели задачи фильтрации флюидов исследован в некоторых работах, особенно для слоистых пластов [3-5].

Пусть задан трехпластовая система, где содержатся экспоненциальные флюиды, при этом считаем что эти пласты гидро-динамически не связаны, и следовательно переток между нижним, средним и верхним пластов отсутствует. В связи с этим связь между ними происходит по стволу единой совместно пробуренной скважины. В отдельных случаях эти пласты могут разрабатывается отдельно пробуренными для каждого пласта скважинами.

Математическая модель сформулированный выше физической задачи можно ставятся так:

Найти непрерывные функции $U(x; t)$, $V(x; t)$ и $W(x; t)$ а также подвижные границы $S_i(x; t)$, $G_i(x; t)$, $R_i(x; t)$ ($i = \overline{1, 2}$) из следующей системы дифференциальных уравнений вида:

$$\frac{\partial}{\partial x} (K_j \exp(-\alpha(|\nabla U|, \beta_j)) H_j \frac{\partial U}{\partial x}) = M_1 \frac{\partial U}{\partial t}, \quad x \in (x_0; L_1), \quad t > 0 \quad (1)$$

$$\frac{\partial}{\partial x} (\bar{K}_j \exp(-\alpha(|\nabla V|, \bar{\beta}_j)) \bar{H}_j \frac{\partial V}{\partial x}) = M_2 \frac{\partial V}{\partial t}, \quad x \in (x_0; L_2), \quad t > 0, \quad (2)$$

$$\frac{\partial}{\partial x} (\bar{\bar{K}}_j \exp(-\alpha(|\nabla W|, \bar{\bar{\beta}}_j)) \bar{\bar{H}}_j \frac{\partial W}{\partial x}) = M_3 \frac{\partial W}{\partial t}, \quad x \in (x_0; L_3), \quad t > 0, \quad j = \overline{1, 3}, \quad (3)$$

с начальными

$$U(x, 0) = \varphi_0(x), V(x, 0) = \psi_0(x), W(x, 0) = \chi_0(x) \quad (4)$$

$$S_i(x, 0) = \bar{S}_i(x, 0), \quad G_i(x, 0) = \bar{G}_i(x, 0), \quad R_i(x, 0) = \bar{R}_i(x, 0) \quad i = \overline{1, 2} \quad (5)$$

а также условиями на подвижных границах:

$$\begin{aligned} a_1 K_1 \exp(-\alpha(|\nabla U|, \beta_1)) H_1 \frac{\partial U}{\partial x} \Big|_{x=S_1-0} &= \\ &= a_1 K_2 \exp(-\alpha(|\nabla U|, \beta_2)) H_1 \frac{\partial U}{\partial x} \Big|_{x=S_1+0} \end{aligned} \quad (6)$$

$$\begin{aligned} a_2 K_2 \exp(-\alpha(|\nabla U|, \beta_2)) H_1 \frac{\partial U}{\partial x} \Big|_{x=S_2-0} &= \\ &= a_1 K_3 \exp(-\alpha(|\nabla U|, \beta_3)) H_1 \frac{\partial U}{\partial x} \Big|_{x=S_2+0} \end{aligned} \quad (7)$$

$$b_1 \bar{K}_1 \exp(-\alpha(|\nabla V|, \bar{\beta}_1)) H_2 \frac{\partial V}{\partial x} \Big|_{x=G_1-0} =$$

$$= b_1 \bar{K}_2 \exp(-\alpha(|\nabla V|, \bar{\beta}_2)) H_2 \frac{\partial V}{\partial x} \Big|_{x = G_1} + 0, \quad (8)$$

$$\begin{aligned} & b_2 \bar{K}_2 \exp(-\alpha(|\nabla V|, \bar{\beta}_2)) H_2 \frac{\partial V}{\partial x} \Big|_{x = G_2} - 0 = \\ & = b_2 \bar{K}_3 \exp(-\alpha(|\nabla V|, \bar{\beta}_3)) H_2 \frac{\partial V}{\partial x} \Big|_{x = G_2} + 0, \end{aligned} \quad (9)$$

$$\begin{aligned} & c_1 \bar{K}_1 \exp(-\alpha(|\nabla W|, \bar{\beta}_1)) H_3 \frac{\partial W}{\partial x} \Big|_{x = R_1} - 0 = \\ & = c_1 \bar{K}_2 \exp(-\alpha(|\nabla W|, \bar{\beta}_2)) H_3 \frac{\partial W}{\partial x} \Big|_{x = R_1} + 0, \end{aligned} \quad (10)$$

$$\begin{aligned} & c_2 \bar{K}_2 \exp(-\alpha(|\nabla W|, \bar{\beta}_2)) H_3 \frac{\partial W}{\partial x} \Big|_{x = R_2} - 0 = \\ & = c_2 \bar{K}_3 \exp(-\alpha(|\nabla W|, \bar{\beta}_3)) H_3 \frac{\partial W}{\partial x} \Big|_{x = R_2} + 0, \end{aligned} \quad (11)$$

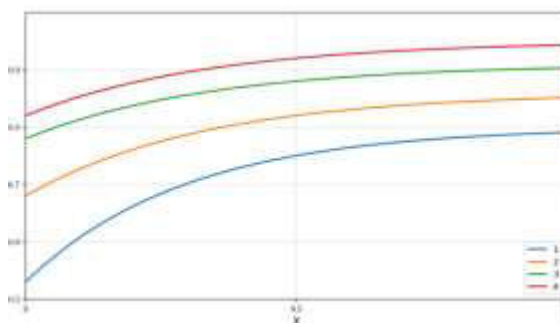
Кроме этих условий на границах возмущений (6) – (11) ставятся и условия на краях области:

$$\begin{aligned} & (\alpha_1 K_1 \exp(-\alpha(|\nabla U|, \beta_1)) \frac{\partial U}{\partial x} + \alpha_2 \bar{K}_1 \exp(-\alpha(|\nabla V|, \bar{\beta}_1)) \frac{\partial V}{\partial x} + \\ & + \alpha_3 \bar{K}_1 \exp(-\alpha(|\nabla W|, \bar{\beta}_1)) \frac{\partial W}{\partial x}) \Big|_{x = x_0} + (\gamma_1 U(x, t) + \gamma_2 V(x, t) + \\ & + \gamma_3 W(x, t)) \Big|_{x = x_0} = \varphi_1(t), \end{aligned} \quad (12)$$

$$\begin{aligned} & b_1 K_1 \exp(-\alpha(|\nabla U|, \beta_1)) \frac{\partial U}{\partial x} \Big|_{x = L_1} = \bar{\psi}_1, \\ & b_2 \bar{K}_2 \exp(-\alpha(|\nabla V|, \bar{\beta}_2)) \frac{\partial V}{\partial x} \Big|_{x = L_2} = \bar{\psi}_2, \end{aligned} \quad (13)$$

$$b_3 K_3 \exp(-\alpha(|\nabla W|, \bar{\beta}_3)) \frac{\partial W}{\partial x} \Big|_{x = L_3} = \bar{\psi}_3 \quad (14)$$

В задаче (1) - (14) коэффициенты и функции, имеет смысл аналогично что и в работах [6-8], функции K_j и $\bar{K}_j$, $\bar{K}_j$ выражают функциональную связь между градиентом давления и скоростью флюида в различных зонах фильтрации и имеет свои аналитические виды аппроксимирующих функций, $\varphi_1(t)$ – объем дебита общей скважины и она содержит в себе суммы величины объема флюидов в стволе скважины, выходящих из каждого пласта в начале координат. Численные алгоритмы задачи (1)-(14) построены с использованием метода итерации (нелинейные коэффициенты в дифференциальных уравнениях линеаризуются), а также метод прямых по переменному t , и потоковой метод прогонки по переменному x , которое приводит к сеточным уравнениям [7,8]. При этом в каждом временном шаге подвижные границы определяется методом челночных итераций [9,10]. Разработанные вычислительные алгоритмы апробированы на гипотетических тестовых данных при $H_i = 0,4$, $\gamma_i = 0$, $\bar{\psi}_i = 0$, $\varphi_i = 1$, $\tau = 0,042$, $\Delta x = 0,005$, $\alpha = -1,4$, $\beta_i = 0,001$, $k = 0,1$, $M = 1$ и результат изменение давления относительно одного пласта приведена на рис.



Распределение давления в одном пласте при $t = 0,1; 0,25; 0,5; 1$ соответственно.

Адекватность и устойчивость разностных уравнений проверена по методу пробных функций. Результаты вычислений показали применимости данной методики и построенных алгоритмов вычислений, для реальных промысловых объектов встречающихся в природе.

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KREMNIY KRISTALI SIRTINING ATOMAR DINAMIKASI VA 3D NANOTUZILMALAR SHAKLLANISHINING NAZARIY PRINSIPLARI ASOSLARI

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Annotatsiya: Mazkur ilmiy maqolada kremniy (Si) kristali sirtining atomar darajadagi strukturaviy o'zgarishlari, xususan, sirt rekonstruksiya jarayonlari va past o'lchamli 3D nanotuzilmalarning shakllanish mexanizmlari nazariy jihatdan tadqiq etiladi. Tadqiqotda sirt

energiyasining minimallasuvi, kvant chegaralanish effektlarining 3D tizimlar xossalariga ta'siri hamda panjaralararo nomutanosiblik natijasida yuzaga keladigan elastik kuchlanishlar tahliliy yoritilgan.

Kalit so'zlar: 3D nanotuzilmalar, kvant chegaralanish effekti, Shredinger tenglamasi, energetik sathlar, taqiqlangan zona kengligi, nanoelektronika, kvant nuqtalar.

Аннотация: В данной научной статье теоретически исследованы структурные изменения кристалла кремния (Si) на атомном уровне, в частности, процессы восстановления поверхности и механизмы формирования низкоразмерных 3D-наноструктур. В исследовании анализируются минимизация поверхностной энергии, влияние квантового ограничения на свойства трехмерных систем, а также аналитический анализ упругих напряжений, возникающих из-за несоответствия решеток.

Ключевые слова: 3D-наноструктуры, эффект квантового ограничения, уравнение Шрёдингера, энергетические уровни, запрещенная зона, нанoelektronika, квантовые точки.

Abstract: This scientific article theoretically studies the structural changes of the silicon (Si) crystal surface at the atomic level, in particular, the processes of surface restoration and the formation mechanisms of low-dimensional 3D nanostructures. In the study, surface energy minimization, the influence of quantum confinement effects on the properties of 3D systems, and elastic stresses resulting from lattice mismatches are analyzed analytically.

Keywords: 3D nanostructures, quantum confinement effect, Schrodinger equation, energy levels, band gap width, nanoelectronics, quantum dots.

I. Kirish: Nanoelektronikaning dolzarb masalalari

Jahonda zamonaviy elektronika sanoati sohasida komponentlarning integral zichligini oshirish va energiya sarfini kamaytirish maqsadida elementlar o'lchamini kichik nano-o'lchamlarga keltirish muhim ahamiyat kasb etadi. Kremniy kristallari yarimo'tkazgichli uskunalarni yaratishda o'zining kimyoviy va termodinamik barqarorligi tufayli asosiy vosita sifatida qayd etiladi [1, 8].

O'lchamlarning nanometrik holatga o'tishi jismning hajmiy xarakteristika parametrlarini ikkinchi darajaga tushishi natijasida sirt effektlari tizimlarining fizik xususiyatlariga ta'sir ko'rsatadi. Sirt-hajm nisbatining ortishi mitti qurilmalarda kvant mexanik qonuniyatlarning ustunligini ta'minlaydi, bu esa sirtning atomar tuzilishini chuqur o'rganishni talab etadi.

II. Kremniy (Si) sirtining atomar rekonstruksiya.

Kristall panjaraning sirt qismida uzilishi natijasida ichki qatlamlarda mavjud bo'lgan periodik atom tuzilishi buziladi. Natijada sirt atomlari o'zining barcha qo'shni atomlari bilan to'liq bog'langan olmay qoladi va to'yinmagan valent bog'lar, ya'ni "uzilgan bog'lar" (dangling bonds) hosil bo'ladi. Bunday bog'larning paydo bo'lishi sirt energiyasining keskin ortishiga sabab bo'ladi. Tizimlarning muntazam minimal erkin energiyali holatga intilishi uning energetik jihatdan termodinamik barqaror holatini o'zgarishiga sabab bo'ladi. Shu sababli sirt atomlari o'zaro qayta taqsimlanadi, atomlararo masofalar va bog'lanish burchaklari o'zgaradi hamda natijada yangi energetik muvozanat holati yuzaga keladi. Ushbu jarayon sirt rekonstruksiya deb ataladi [2–3].

Sirt rekonstruksiya jarayonida kristallning yuqori qatlamidagi atomlar o'zining dastlabki ideal panjara holatidan chetga chiqadi va yangi geometrik konfiguratsiyalar hosil qiladi. Bu o'zgarishlar sirtning elektron, optik va fizik-kimyoviy xossalariga sezilarli ta'sir ko'rsatadi. Yarimo'tkazgichdan tayyorlangan materiallarda rekonstruksiya tufayli sirtning elektr o'tkazuvchanligi, elektron holatlar zichligi bilan birgalikda gaz, suyuqlik yoki eritmadagi atom va molekullarning boshqa modda sirtiga yig'ilishi jarayoni o'zgaradi. Bu holatlar tufayli nanoelektronika, sensor texnologiyalari va kvant qurilmalarini yaratishda sirt rekonstruksiya muhim vosita hisoblanadi. Atomlarning energetik jihatdan barqaror holatni egallashida kristall sirtida yuz beradigan rekonstruksiya jarayonlari muhim ahamiyat kasb etadi. Kremniy (Si) kristallining (100) yoki (111) sirtlarida atomlar murakkab rekonstruksiya strukturalarini yuzaga keltirish holatlari kuzatilishi mumkin. Mazkur omillar tufayli sirt energiyasi kamayadi hamda tizim barqaror holatga o'tadi. Fizikaning sirtlarga oida sohalari va materialshunoslikka oid ilmiy tadqiqotlarida ushbu jarayonlarni o'rganish yangicha turdagi funksional materiallar yaratishda ustuvor yo'nalishlardan biri sifatida hisoblanadi.

Si (111) 7×7 modeli – Kunihiro Takayanagi yaponiyalik taniqli fizik va professor tomonidan taklif etilgan ushbu model sirt fizikasidagi eng murakkab rekonstruksiya turlaridan biridir. U dimerlar, adatomlar va bo'shliqlar kombinatsiyasi orqali sirt energiyasini minimallashtiradi. Bu model sirtning barqarorligini ta'minlashda asosiy rol o'ynaydi [3].

Si (100) 2×1 modeli: Zamonaviy planar tranzistorlar texnologiyasida (CMOS) eng keng qo'llaniladigan yuzadir. Bunda qo'shni sirt atomlari juftlashib dimerlar hosil qiladi, natijada sirtning davriyligi o'zgaradi va elektronlarning sirt bo'ylab harakatchanligiga ta'sir ko'rsatadi [4, 9].

III. 3D nanotuzilmalarning shakllanish mexanizmlari.

Kremniy asosidagi 3D tuzilmalar (nanosimlar, nanonaychalar va kvant nuqtalari) o'stirish jarayonida atomar darajadagi o'z-o'zidan tashkil topish prinsiplariga tayanadi.

III.1. Termodinamik yondashuv – Stranski-Krastanov mexanizmi.

Geteroepitaksial o'stirish jarayonida, masalan, kremniy (Si) yuzasiga germaniy (Ge) qatlamini yotqizishda, ikki materialning panjara doimiylari orasidagi farq elastik kuchlanishni keltirib chiqaradi [5, 11]. Qatlam ma'lum bir "kritik qalinlikka" erishganda, tizim energiyani kamaytirish uchun tekis qatlamdan 3D kvant nuqtalari (orolchalar) hosil qilishga intiladi. Bu jarayon moddaning energetik jihatdan eng qulay holatga o'tishidir.

III.2. Kvant mexanik effektlar va chegaralanish.

3D nanotuzilmalarda elektronlarning harakat erkinligi uchta koordinata o'qi bo'yicha ham cheklanadi. Bunday tizimlarning energetik holati fundamental Shredinger tenglamasi orqali tavsiflanadi:

$$\hat{H}\Psi = E\Psi$$

bunda, $\hat{H}$ -tizimning Hamilton operatori, Ψ -zarrachaning to'liq funksiyasi, E - energetik sath qiymati hisoblanadi.

Zarrachaning nano-o'lchamli fazoda chegaralanishi natijasida energetik sathlar diskret ko'rinishga o'tadi va materialning taqiqlangan zona kengligi E_g esa ortadi. Bu hodisa esa nano-qurilmalarning optik va elektr xossalarini boshqarish imkoniyatini beradi [6, 12].

IV. Potensial to'siq dinamikasi va tunnel effekti.

Kremniy asosidagi 3D strukturalarda elektronlar bir hududdan ikkinchi hududga o'tishda klassik fizikada "o'tib bo'lmas" deb hisoblangan energetik to'siqlarni tunnel effekti yordamida yengib o'tadi. Tashqi kuchli elektr maydoni ta'sirida sirt potensial to'sig'i yupqalashadi va qiyshayadi.

O'tish ehtimolligi T quyidagi eksponentsial qonuniyatga bo'ysunadi:

$$T \approx e^{-2\kappa l}.$$

bunda, l – to'siqning geometrik kengligi, κ (kappa) – to'liq funksiyasining so'nish koeffitsienti. Ushbu effekt nano-miqyosdagi qurilmalarning (masalan, tunnel diodlari va flesh-xotiralar) o'ta yuqori tezlikda ishlashini ta'minlaydi [7, 10].

V. Xulosa.

Mazkur tadqiqot natijasida kremniy (Si) sirtidagi atomar rekonstruksiya jarayonlari hamda uch o'lchamli (3D) nanostrukturalarda namoyon bo'ladigan kvant effektlari o'zaro bog'liq jarayon sifatida belgilanishi qayd etildi. Sirt energiyasini boshqarish, elektronlarning tunnel o'tish jarayonlarini modellashtirish hamda kvant holatlarini optimallashtirish orqali yuqori samaradorlikka ega kvant kompyuterlari va yangi avlod quyosh elementlarini yaratish imkoniyatlari sezilarli darajada kengayadi.

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ANIZOTROP PLASTINALARNING TERMO-MAGNITO-ELEKTRO-ELASTIK NOCHIZIQLI DEFORMATSIYALANISHINI R-FUNKSIYALAR USULIDA TADQIQ ETISH

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Annotatsiya: Murakkab shaklli va nostandart geometriyaga ega bo'lgan anizotrop plastinalarning termo-magnito-elektro-elastik (TMEE) o'zaro bog'liq maydonlar ta'siridagi nochiziqli deformatsiyalanish jarayonlarini matematik modellash masalasi ko'rib chiqilgan. Geometrik nochiziqlik va turli fizik maydonlarning uzviy bog'liqligini hisobga olgan holda, jarayonni tavsiflovchi differensial tenglamalar tizimi va mos chegaraviy shartlar shakllantirilgan. Ob'ekt chegarasining murakkabligini to'liq va aniq ifodalash maqsadida V.L. Rvachevning R-funksiyalar usuli (RFM) hamda variatsion metodlar (Ritz yoki Bubnov-Galerkin) kombinatsiyasidan foydalanilgan. Taklif etilayotgan yondashuv murakkab shaklli plastinalarning kuchlanish-deformatsiya holatini yuqori aniqlikda va hisoblash resurslarini tejagan holda tahlil qilish imkonini beradi. Olingan natijalar aqlli materiallar (smart materials) va zamonaviy datchiklar loyihalashda muhim amaliy ahamiyatga ega.

Kalit so'zlar: R-funksiyalar usuli, anizotrop plastina, termo-magnito-elektro-elastiklik, nochiziqli deformatsiya, matematik model, murakkab geometriya, aqlli materiallar, chegaraviy masala.

Gamilton–Ostrogradskiy variatsion prinsipi asosida yuqqa anizotrop plastinaning termo-magnito-elektro-elastiklik maydonlar ta'siridagi nochiziqli va chiziqli deformatsiyalanish jarayonlarining mukammal matematik modeli keltirib chiqarilgan. Plastinaning dinamik harakat tenglamalar tizimini shakllantirishda, qatlamlar bo'ylab ko'chishlarning o'zgarish qonuniyatlarini ifodalash uchun klassik Kirxgof–Lyav gipotezasidan foydalaniladi [1].

$$u_1 = u - z \frac{\partial w}{\partial x}, \quad u_2 = v - z \frac{\partial w}{\partial y}, \quad u_3 = w; \quad (1)$$

Bu yerda : u, v, w – ko'chishlar.

Kirxgof–Lyav gipotezasiga ko‘ra, yuqqa plastina qalinligi bo‘ylab deformatsiyalanish jarayonlari hisobga olinmaydi. Natijada, plastina qalinligi bo‘yicha o‘zgaruvchilar integrallanib, ko‘rilayotgan murakkab uch o‘lchovli (3D) fizik-mexanik masala o‘rta yuzaga nisbatan ikki o‘lchovli (2D) matematik modelga keltiriladi.

Gamilton–Ostrogradskiy tamoyilining umumiy ko‘rinishi [2]:

$$\int_t (\delta K - \delta \Pi + \delta A) dt = 0; \quad (2)$$

Bu yerda: δ – variatsiya; K – kinetik energiya; Π – potensial energiya; A – tashqi hajm va sirt kuchlari bajargan ish.

Kinetik energiyaning variatsiyasini umumiy ko‘rinishi:

$$\begin{aligned} \int_t \delta K = & \int \int_y \left\{ \rho h \frac{\partial u}{\partial t} \delta u + \rho h \frac{\partial v}{\partial t} \delta v + \rho h \frac{\partial w}{\partial t} \delta w \right\} dy dx \Big|_t + \int_y \rho \frac{h^3}{12} \frac{\partial^2 w}{\partial t \partial x} \delta w \Big|_x dy \Big|_t + \\ & + \int_x \rho \frac{h^3}{12} \frac{\partial^2 w}{\partial t \partial y} \delta w \Big|_y dx \Big|_t - \int \int \int_t \left\{ \rho h \frac{\partial^2 u}{\partial t^2} \delta u + \rho h \frac{\partial^2 v}{\partial t^2} \delta v + \rho h \frac{\partial^2 w}{\partial t^2} \delta w \right\} dy dx dt. \end{aligned} \quad (3)$$

Potensial energiyaning variatsiyasini umumiy ko‘rinishi::

$$\begin{aligned} \delta \Pi = & \int_y \left\{ N_{11} \delta u - M_{11} \delta \frac{\partial w}{\partial x} + \frac{\partial M_{11}}{\partial x} \delta w + N_{11} \frac{\partial w}{\partial x} \delta w + \frac{1}{2} N_{12} \delta v - \frac{1}{2} M_{12} \delta \frac{\partial w}{\partial y} + \frac{1}{2} \frac{\partial M_{12}}{\partial y} \delta w + \right. \\ & + \frac{1}{2} N_{12} \frac{\partial w}{\partial y} \delta w \left. \right\} dy \Big|_x + \int_x \left\{ N_{22} \delta v - M_{22} \delta \frac{\partial w}{\partial y} + \frac{\partial M_{22}}{\partial y} \delta w + N_{22} \frac{\partial w}{\partial y} \delta w + \frac{1}{2} N_{12} \delta u + \frac{1}{2} \frac{\partial M_{12}}{\partial x} \delta w - \right. \\ & - \frac{1}{2} M_{12} \delta \frac{\partial w}{\partial x} + \frac{1}{2} N_{12} \frac{\partial w}{\partial x} \delta w \left. \right\} dx \Big|_y - \int \int_y \left\{ \frac{\partial N_{11}}{\partial x} \delta u + \frac{1}{2} \frac{\partial N_{12}}{\partial y} \delta u + \frac{\partial N_{22}}{\partial y} \delta v + \frac{1}{2} \frac{\partial N_{12}}{\partial x} \delta v + \right. \\ & + \frac{\partial}{\partial x} \left(N_{11} \frac{\partial w}{\partial x} + \frac{1}{2} N_{12} \frac{\partial w}{\partial y} \right) \delta w + \frac{\partial}{\partial y} \left(N_{22} \frac{\partial w}{\partial y} + \frac{1}{2} N_{12} \frac{\partial w}{\partial x} \right) \delta w + \frac{\partial^2 M_{11}}{\partial x^2} \delta w + \frac{\partial^2 M_{12}}{\partial x \partial y} \delta w + \frac{\partial^2 M_{22}}{\partial y^2} \delta w \left. \right\} dx dy. \end{aligned} \quad (4)$$

Tashqi kuchlar bajargan ish variatsiyasi:

$$\begin{aligned} \int_t \delta A dt = & \int \int \int_t \left[(N_x + p_x^{em} + q_x + T_{zx}) \delta u + (N_y + p_y^{em} + q_y + T_{zy}) \delta v + (N_z + p_z^{em} + q_z + T_{zz}) \delta w \right] dx dy dt \\ & + \int \int_y \left[(N_{Px} + N_{Txx}) \delta u + (N_{Py} + N_{Txy}) \delta v + (N_{Pz} + N_{Txz}) \delta w \right] \Big|_x dy dt + \\ & + \int \int_x \left[(N_{Fy} + N_{Tyx}) \delta u + (N_{Fy} + N_{Tyy}) \delta v + (N_{Fz} + N_{Tyz}) \delta w \right] \Big|_y dx dt \end{aligned} \quad (5)$$

Natijada, tizim uchun alohida aniqlangan potensial va kinetik energiyalar variatsiyalarini hamda tashqi kuchlarning bajargan ishi variatsiyasini (2) funksional ifodasiga keltirib qo‘yish orqali anizotrop plastinaning umumiy noxiziqli dinamik harakat tenglamalari tizimi hosil qilinadi. [2].

$$\left\{ \begin{aligned} \rho h \frac{\partial^2 u}{\partial t^2} + \frac{\partial N_{11}}{\partial x} + \frac{1}{2} \frac{\partial N_{12}}{\partial y} + p^{\text{em}}_x + N_x + q_x + T_{zx} &= 0 \\ \rho h \frac{\partial^2 v}{\partial t^2} + \frac{\partial N_{22}}{\partial y} + \frac{1}{2} \frac{\partial N_{12}}{\partial x} + p^{\text{em}}_y + N_y + q_y + T_{zy} &= 0 \\ \rho h \frac{\partial^2 w}{\partial t^2} + \frac{\partial^2 M_{11}}{\partial x^2} \delta w + \frac{\partial^2 M_{12}}{\partial x \partial y} \delta w + \frac{\partial^2 M_{22}}{\partial y^2} \delta w + p^{\text{em}}_z + N_z + q_z + T_{zz} &= 0, \end{aligned} \right. \quad (6)$$

Boshlang'ich shartlar:

$$\rho h \frac{\partial u}{\partial t} \Big|_t = 0, \rho h \frac{\partial v}{\partial t} \Big|_t = 0, \rho h \frac{\partial w}{\partial t} \Big|_t = 0. \quad (7)$$

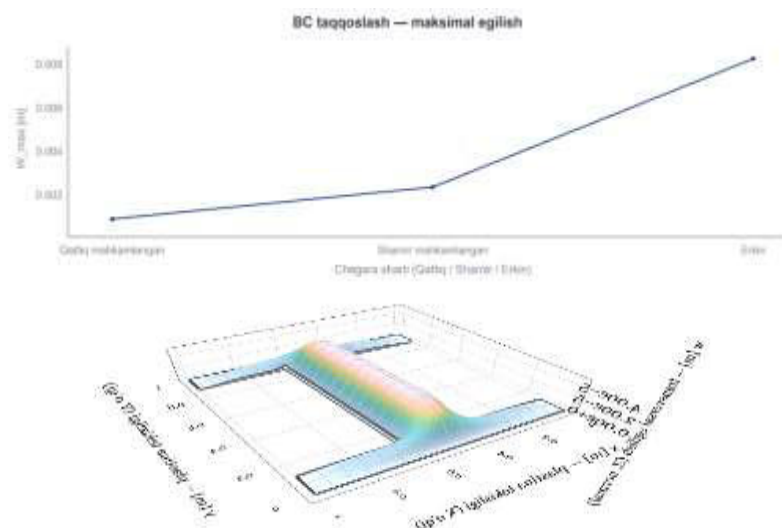
Chegaraviy shartlar:

$$\begin{aligned} N_{11} \delta u|_x &= 0, \frac{1}{2} N_{12} \delta v|_x = 0, -M_{11} \delta \frac{\partial w}{\partial x} \Big|_x = 0, -\frac{1}{2} M_{12} \delta \frac{\partial w}{\partial y} \Big|_x = 0, \\ \left[N_{11} \frac{\partial w}{\partial x} + \frac{1}{2} N_{12} \frac{\partial w}{\partial y} - \frac{\partial M_{11}}{\partial x} - \frac{1}{2} \frac{\partial M_{12}}{\partial y} \right] \delta w \Big|_x &= 0, \\ \left[(N_{Px} + N_{Txx}) \delta u + (N_{Py} + N_{Txy}) \delta v + (N_{Pz} + N_{Tzx}) \delta w \right] \Big|_x &= 0, \\ N_{22} \delta v|_y &= 0, \frac{1}{2} N_{12} \delta u|_y = 0, -M_{22} \delta \frac{\partial w}{\partial y} \Big|_y = 0, -\frac{1}{2} M_{12} \delta \frac{\partial w}{\partial x} \Big|_y = 0, \\ \left[N_{22} \frac{\partial w}{\partial y} + \frac{1}{2} N_{12} \frac{\partial w}{\partial x} - \frac{\partial M_{22}}{\partial y} - \frac{1}{2} \frac{\partial M_{12}}{\partial x} \right] \delta w \Big|_y &= 0, \\ \left[(N_{Fy} + N_{Tyx}) \delta u + (N_{Fy} + N_{Tyx}) \delta v + (N_{Fz} + N_{Tyz}) \delta w \right] \Big|_y &= 0. \end{aligned} \quad (8)$$

Hisoblash tajribasi: Tadqiq qilinayotgan I-shaklidagi anizotrop plastina ichki chegaralaridan sharnirli mahkamlanib, tashqi chegaralari esa ketma-ket 'Qattiq', 'Sharnir', 'Erkin' holatda o'lchamlari har hil holatlarda tajribalar o'tkazildi. Chegaralari: tashqi — Qattiq mahkamlangan, ichki — Sharnir mahkamlangan. — Taqqoslash: tashqi BC variantlari (grafik — sidebar dagi joriy tashqi BC).

I-jadval.

I-shaklidagi anizotrop plastina o'lchamlari o'zgarishi asosida olingan natijalar				
z, m	w_d, m	$w_{d, min}$	w_B, m	$w_{B, min}$
0	0.000282	0.2825	0.000911	0.9106
0.05	0.000165	0.1652	0.00056	0.5602
0.1	0.00007	0.0703	0.000269	0.2688
0.15	0.000013	0.0127	0.000077	0.0767
0.2	0.000001	0.0008	0.00001	0.0096
0.25	0.000035	0.0352	0.000079	0.0794
0.3	0.000107	0.1069	0.000283	0.2827
0.35	0.000198	0.1983	0.000595	0.5949
0.4	0	0	0	0
0.45	0	0	0	0
0.5	0	0	0	0
0.55	0	0	0	0
0.6	0	0	0	0
0.65	0.000198	0.1984	0.000595	0.5949
0.7	0.000107	0.107	0.000283	0.2827
0.75	0.000035	0.0354	0.000079	0.0795
0.8	0.000001	0.001	0.00001	0.0096
0.85	0.000013	0.0128	0.000077	0.0767
0.9	0.00007	0.0704	0.000269	0.2688
0.95	0.000165	0.1653	0.00056	0.5602
1	0.000282	0.2825	0.000911	0.9106



Olingan grafik 2D va 3D model natijalari shuni ko'rsatadiki, I-shakldagi murakkab geometriyaga ega plastinalarni loyihalashda tashqi chegara shartlarini qat'iy (qattiq) mahkamlash konstruksiya mustahkamligini ta'minlash va chiziqli bo'lmagan deformatsiyalarni (egilishlarni) minimal darajada ushlab turish uchun eng samarali usul hisoblanadi. Chegara shartlarining qattiq holatdan erkin holatga o'tishi maksimal egilishning bir necha barobar keskin ortishiga olib keladi.

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MATHEMATICAL OPTIMIZATION OF MULTISTAGE LAUNCH VEHICLES: A CALCULUS-BASED APPROACH

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Abstract. The design of modern aerospace launch vehicles, such as the *Saturn V*, relies on staging to systematically discard depleted mass and achieve requisite orbital or escape velocities. This article explores the mathematical optimization of a three-stage rocket designed to propel a payload of mass A into space. Utilizing the Tsiolkovsky rocket equation and the method of Lagrange multipliers, we derive exact analytical expressions to minimize the total rocket engine mass M while satisfying strict terminal velocity constraints. We subsequently apply these models to two practical scenarios: achieving a 100-mile Earth orbit and escaping Earth's gravitational field entirely.

1. Introduction and The Rocket Equation

For a single-stage rocket consuming fuel at a constant rate, the change in velocity (∇V) resulting from the vehicle's acceleration is modeled by the equation:

$$\nabla V = -c \ln \left(1 - \frac{(1-S)M_r}{P + M_r} \right)$$

In this model, M_r represents the mass of the rocket engine (including initial fuel), P is the mass of the payload, c is the constant speed of the exhaust relative to the rocket, and S is the

structural factor. The structural factor is determined by the rocket's design and is defined as the ratio of the rocket vehicle's mass without fuel to its total mass with fuel.

To optimize a three-stage rocket, we assume outside forces (like gravity and atmospheric drag) are negligible and that both c and S remain constant across all three stages. Let M_i denote the mass of the i th stage engine. The payload for the first stage is the combined mass of the second stage, third stage, and the final payload A (i.e., $M_2 + M_3 + A$). Applying the velocity equation to all three stages consecutively, the final terminal velocity v_f attained after all three stages have jettisoned is the sum of the individual velocity changes:

$$v_f = c \left[\ln \left(\frac{M_1 + M_2 + M_3 + A}{SM_1 + M_2 + M_3 + A} \right) + \ln \left(\frac{M_2 + M_3 + A}{SM_2 + M_3 + A} \right) + \ln \left(\frac{M_3 + A}{SM_3 + A} \right) \right]$$

2. Simplifying the Optimization Constraint

Our objective is to minimize the total mass of the rocket engines, $M = M_1 + M_2 + M_3$, subject to the constraint that the rocket achieves the desired velocity v_f . Because the current expression is difficult to use with Lagrange multipliers, we introduce substitution variables N_i to represent the logarithmic arguments:

$$N_1 = \frac{M_1 + M_2 + M_3 + A}{SM_1 + M_2 + M_3 + A}, N_2 = \frac{M_2 + M_3 + A}{SM_2 + M_3 + A}, N_3 = \frac{M_3 + A}{SM_3 + A}$$

This drastically simplifies our velocity constraint equation to: $v_f = c(\ln N_1 + \ln N_2 + \ln N_3)$

By isolating the individual mass ratios algebraically, we find that:

$$\frac{M_1 + M_2 + M_3 + A}{M_2 + M_3 + A} = \frac{(1-S)N_1}{1-SN_1}, \frac{M_2 + M_3 + A}{M_3 + A} = \frac{(1-S)N_2}{1-SN_2}, \frac{M_3 + A}{A} = \frac{(1-S)N_3}{1-SN_3}$$

By multiplying these three expressions together, the intermediate terms cancel out, leaving us with a streamlined equation representing the total mass ratio of the launch vehicle:

$$\frac{M + A}{A} = \frac{(1-S)^3 N_1 N_2 N_3}{(1-SN_1)(1-SN_2)(1-SN_3)}$$

3. Applying Lagrange Multipliers

Because the natural logarithm is a monotonically increasing function, minimizing $\ln \left(\frac{M+A}{A} \right)$ occurs at the exact same location as minimizing M . We construct our optimization problem using the objective function f and constraint function g :

$$f(N_1, N_2, N_3) = \ln \left(\frac{(1-S)^3 N_1 N_2 N_3}{(1-SN_1)(1-SN_2)(1-SN_3)} \right)$$

$g(N_1, N_2, N_3) = c(\ln N_1 + \ln N_2 + \ln N_3) = v_f$. Using the properties of logarithms, we expand f to make differentiation simpler:

$$f = 3 \ln(1-S) + \ln N_1 + \ln N_2 + \ln N_3 - \ln(1-SN_1) - \ln(1-SN_2) - \ln(1-SN_3)$$

Setting up the Lagrange multiplier equation $\nabla f = \lambda \nabla g$, we take the partial derivative with respect to N_1 :

$$\frac{df}{dN_1} = \frac{1}{N_1} + \frac{S}{1-SN_1} = \frac{1-SN_1+SN_1}{N_1(1-SN_1)} = \frac{1}{N_1(1-SN_1)}, \frac{dg}{dN_1} = \frac{c}{N_1}$$

Equating the two via the multiplier λ yields:

$$\frac{1}{N_1(1-SN_1)} = \lambda \frac{c}{N_1} \Rightarrow \frac{1}{(1-SN_1)} = \lambda c$$

Because this identical mathematical relationship exists for N_2 and N_3 , we conclude that minimum mass occurs when $N_1 = N_2 = N_3 = N$.

Substituting N back into the constraint equation provides: $v_f = 3c \ln N \Rightarrow \ln N = \frac{v_f}{3c} \Rightarrow N = e^{\frac{v_f}{3c}}$

We can now express the absolute minimum total engine mass M exclusively as a function of the target velocity v_f :

$$M(v_f) = A \left[\left(\frac{(1-S)e^{\frac{v_f}{3c}}}{1 - Se^{\frac{v_f}{3c}}} \right)^3 - 1 \right]$$

4. Results and Real-World Applications

To evaluate the mathematical model, we apply the derived formulas to a three-stage rocket utilizing a structural factor of $S=0.2$ and an exhaust speed of $c=6000$ mile/hours. Let R define the mass ratio multiplier for each successive stage, where $R=\frac{(1-S)N}{1-SN}$, Scenario A: Low Earth Orbit, To place the rocket into orbit **100** miles above the earth, it requires a final velocity of $v_f=17500$ mile/hours.

1. Calculate N : $N=e^{\frac{17500}{18000}} \approx 2.6438$.

2. Calculate Ratio R : $R=\frac{0.8(2.6438)}{1-0.2(2.6438)} \approx \frac{2.115}{0.4712} \approx 4.4884$

3. Total Minimum Mass: $M=A(R^3 - 1) = A(4.4884^3 - 1) = 89.418A$.

5. Conclusion

Through the application of multivariable calculus and Lagrange multipliers, we demonstrate that the mass distribution of a multistage rocket is highly non-linear. Escaping Earth's gravity requires exponentially more mass distributed to the first stage compared to achieving low Earth orbit. This analytical framework provides aerospace engineers with an exact optimization threshold, serving as the critical first step before integrating external variables such as atmospheric drag and trajectory pitch angles.

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ON THE ASYMPTOTIC BEHAVIOUR OF SOLUTIONS TO A NON-DIVERGENT NONLINEAR PARABOLIC SYSTEM WITH ABSORPTION

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RESUME. In this paper, the asymptotic behavior of self-similar solutions to the Cauchy problem for a system of nonlinear parabolic equations in non-divergence form is obtained.

Keywords: mathematical modeling, self-similar solutions, parabolic equations, non-divergence form, asymptotic behavior.

In this work, in the domain $Q = \{(t, x): t > 0, x \in R\}$ we consider the Cauchy problem for a system of nonlinear parabolic equations not in divergence form:

(1)

$$\begin{cases} |x|^\epsilon \frac{\partial u}{\partial t} = u^{\alpha_1} \frac{\partial}{\partial x} \left(u^{m-1} \frac{\partial u}{\partial x} \right) - |x|^\epsilon v^{\beta_1}, \\ |x|^\epsilon \frac{\partial v}{\partial t} = v^{\alpha_2} \frac{\partial}{\partial x} \left(v^{m-1} \frac{\partial v}{\partial x} \right) - |x|^\epsilon u^{\beta_2}, \end{cases}$$

$$\begin{cases} u(0, x) = u_0(x) \geq 0, \\ v(0, x) = v_0(x) \geq 0. \end{cases} \quad (2)$$

where $\beta_1 > 1, \beta_2 > 1, m > 1, \alpha_1 > 1, \alpha_2 > 1, \ell > 0$ - numerical parameters, $u = u(t, x) \geq 0$, $v = v(t, x) \geq 0$ - are the solutions.

The qualitative properties of solutions to nonlinear parabolic systems of this type have been investigated by various authors [1,2].

Here, we introduce the notations:

$$c_{i1} = \frac{1 - \alpha_i}{(\alpha_i + m - 1)^2}, \quad c_{i2} = \frac{B_i^{1-\alpha_1-m}}{(\ell + 2)^2(\alpha_i + m - 1)}, \quad c_{i3} = -\frac{d_i B_{3-i}^{\beta_i}}{(\ell + 2)^2 B^{\alpha_i+m}},$$

$$\zeta_i = \frac{\beta_i}{\alpha_{3-i} + m - 1} - \frac{1}{\alpha_i + m - 1} + 1, \gamma = n_1(\alpha_1 + m - 1) + 1, b_i = A_i B_i \quad (i = 1, 2)$$

Let $y(\eta) = y^0 + o(1)$, $z(\eta) = z^0 + o(1)$ as $\eta \rightarrow +\infty$ and the equality $n_2(\alpha_2 + m - 1) = n_1(\alpha_1 + m - 1)$ is performed.

Theorem 1. Let $\zeta_1 > 0, \zeta_2 > 0$. The compactly supported solution to problem (1)-(2) has the following asymptotic behavior as $x \rightarrow a^{\frac{1}{2}}(t - T)^{\frac{\gamma}{2}}$:

$$u_A(t, x) \simeq b_1(T - t)^{-n_1} \left(a - \frac{\gamma x^{\ell+2}}{A_1^{\alpha_1+m-1}(T - t)^\gamma} \right)^{\frac{1}{\alpha_1+m-1}} (y^0 + o(1)),$$

$$v_A(t, x) \simeq b_2(T - t)^{-n_2} \left(a - \frac{\gamma x^{\ell+2}}{A_2^{\alpha_2+m-1}(T - t)^\gamma} \right)^{\frac{1}{\alpha_2+m-1}} (z^0 + o(1)),$$

where $0 < y^0 < +\infty$ and $0 < z^0 < +\infty$ are the solutions of the following nonlinear algebraic system:

$$c_{11} w_1^{\alpha_1+m} + c_{12} w_1 + c_{13} w_2^{\beta_1} = 0,$$

$$c_{21} w_2^{\alpha_2+m} + c_{22} w_2 + c_{23} w_1^{\beta_2} = 0. \quad (4)$$

The aim of this study is to establish the asymptotic behavior of self-similar solutions and to obtain estimates for solutions of problem (1)–(2) using self-similar analysis.

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STABILITY OF THE NUMERICAL SOLUTION OF THE MIXED PROBLEM FOR THE AW–RASCLE–ZHANG EQUATIONS

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Abstract. This paper considers the construction of a finite difference scheme for the Aw–Rascle–Zhang (ARZ) system in Riemann coordinates and investigates the stability of the numerical solution using a discrete Lyapunov function. An upwind approximation scheme for a mixed boundary value problem is proposed, taking into account the propagation direction of characteristic

waves. Exponential decay of the solution energy under stability conditions is proved. The obtained results can be applied to traffic flow modeling and other processes described by hyperbolic systems.

Keywords: hyperbolic systems, Aw–Rascle–Zhang model, Lyapunov function, stability, numerical methods.

Introduction. Hyperbolic systems of differential equations are widely used for modeling transport flows, wave propagation, and transfer processes. One of the most important models is the Aw–Rascle–Zhang (ARZ) system, which takes into account both traffic density and vehicle velocity. Ensuring the stability of numerical methods for solving such systems remains an essential problem.

The Lyapunov method is an effective tool for stability analysis. Constructing a discrete Lyapunov function makes it possible to study the behavior of numerical solutions and obtain estimates for energy dissipation in the system.

Problem Formulation

Consider the Aw–Rascle–Zhang system:

$$\begin{cases} \rho_t + (\rho u)_x = 0 \\ (v + \wp(\rho))_t + u(v + \wp(\rho))_x = 0, \end{cases}$$

where $\rho(x, t)$ denotes traffic density and $u(x, t)$ represents vehicle velocity.

For analysis, the system is transformed into Riemann coordinates, after which diagonalization is performed and an upwind finite difference scheme is constructed according to the direction of characteristics.

Construction of the Lyapunov Function

To investigate stability, a discrete Lyapunov function is introduced in the form of weighted energy:

$$E^n = \sum_{i=0}^N \left[\alpha_1 e^{-\mu x_i} (w_{1,i}^n)^2 + \alpha_2 e^{\mu x_i} (w_{2,i}^n)^2 \right] \Delta x,$$

The choice of weighting coefficients depends on the direction of characteristic propagation. This approach allows one to consider the properties of hyperbolic systems and obtain dissipative behavior of the numerical scheme.

Research Results

Numerical experiments show:

- correct propagation of waves along characteristics;
- absence of spurious oscillations;
- monotonic decrease of discrete energy;
- exponential decay of the Lyapunov function;
- stability of the scheme under the CFL condition.

The obtained results fully agree with theoretical stability estimates.

Conclusion

An upwind finite difference scheme for the mixed problem of the Aw–Rascle–Zhang system in Riemann coordinates has been constructed, and a discrete Lyapunov function has been developed for stability analysis. Exponential decay of the solution energy has been proved, confirming the stability of the numerical method.

The proposed approach can be extended to nonlinear hyperbolic systems and traffic flow control problems.

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KOMPYUTER O‘YINLARIDA VA VIRTUAL SIMULYATSIYALARDA FUNDAMENTAL FIZIKA-MATEMATIK MODELLARNING O‘RNI

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Annotatsiya: Ushbu maqola kompyuter o‘yinlari va fundamental fanlar ya’ni, fizika-matematika bilan bog‘liqligiga bag‘ishlanadi. Fizik jarayonlarni kompyuter modellash tirish orqali vizuallashtirishning ta’limiy va texnik ahamiyati yoritilgan. Tadqiqot doirasida kinematika qonunlari asosida jismning harakat algoritmi ishlab chiqilgan va mashhur "Chrome Dino" o‘yini misol qilingan.

Kalit so‘zlar: Kinematika, vektorli matematika, differensial tenglamalar, algoritmik fikrlash, simulyatsiya, Katta sonlar qonuni (KSQ), Physics Engine.

KIRISH

Zamonaviy texnologik innovatsiyalar ko‘pincha yangi algoritmlar va matematik teoremlarga tayanadi. Ravshanki, matematika kompyuter tizimlari va algoritmlari bilan shug‘ullanadigan mutaxassislar uchun fundamental vosita hisoblanadi [1-3]. Kompyuter o‘yinlari nafaqat ko‘ngilochar vosita, balki matematikaning ko‘plab sohalari va fizikaning qonunlari birlashgan murakkab tizimdir.

Bunga yaqqol misol sifatida 2014-yilda Sebastien Gabriel tomonidan yaratilgan Google Chrome brauzerining "T-Rex Runner" (Dino Run) o‘yinini keltirish mumkin. Ushbu o‘yin garchi sodda ko‘rinsada, biroq Nyuton mexanikasi va matematik modellarga tayanadi. Maqolaning maqsadi shundan iboratki, o‘yin dunyosining ushbu bizga "ko‘rinmas qonunlari" qanday ishlashini nazariy va amaliy jihatdan ifoda etishdan iborat.

ASOSIY QISM

O‘yin fizikasini yaratishda quyidagi fundamental matematik va fizik modellar qo‘llaniladi:

Ob’ektning fazodagi o‘rni $P(x, y, z)$ koordinatalari bilan belgilanadi. Harakatni ifodalash uchun vektorlar qo‘llaniladi [5]. Jismning yangi pozitsiyasini hisoblash quyidagi vektorli qo‘shishga asoslanadi:

$$P_{new} = P_{old} + V * \Delta t$$

Bunda V — tezlik vektori, Δt — vaqt oralig‘i. Jismning boshqa parametrlarini ham fizik formulalar bilan ifodalash mumkin. Jismning tezlanishi (a) va uning vaqt bo‘yicha o‘zgarishi

differensial tenglamalar orqali ifodalanadi [4]. O'yinda gravitatsiya ta'siridagi harakat quyidagicha modellashtiriladi:

$$\frac{dv}{dt} = g \rightarrow v(t) = v_0 + gt, \frac{dy}{dt} = v \rightarrow y(t) = y_0 + v_0 t + \frac{1}{2}gt^2$$

Dinozavr kaktus ustidan muvaffaqiyatli sakrab o'tishi uchun o'yin dvigateli har bir parametrni aniq belgilashi shart. Faraz qilaylik, o'yin kodi (60 FPS — kadr/soniya tezligida) quyidagi standart qiymatlarga ega:

Boshlang'ich vertikal sakrash tezligi (impuls): $v_0 = 12.5 \frac{\text{piksel}}{\text{kadr}}$

O'yin gravitatsiyasi: $g = 0.6 \text{ piksel/kadr}^2$

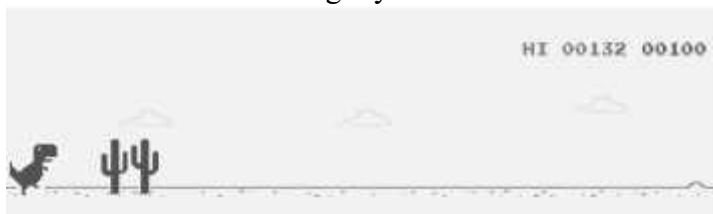
Dinozavrning eng yuqori balandlikka ($v = 0$) chiqish vaqti (t):

$$t = \frac{v_0}{g} = \frac{12.5}{0.6} \approx 20.8 \text{ kadr}$$

Sakrashning maksimal balandligi ($h_{\max}$):

$$h_{\max} = \frac{v_0^2}{2g} = \frac{12.5^2}{2 * 0.6} = \frac{156.25}{1.2} \approx 130 \text{ piksel}$$

Dasturlashning mantiqiy yo'nalishi shundan iboratki, dinozavr yuqoriga chiqish uchun 20.8 kadr va yerga qaytib tushish uchun yana 20.8 kadr sarflaydi. Jami havoda bo'lish vaqti $\approx 20.8 \text{ kadr}$ ni tashkil etadi. Bu 60 FPS chastotada taxminan 0.69 soniyaga teng. Bu o'yin dasturida kaktuslar orasidagi minimal matematik limitni belgilaydi.



1-rasm. "Chrome Dino" o'yinining grafik interfeysi va to'siqlarni aniqlash (hitbox) tasviri.

XULOSA.

Shunday qilib, kompyuter o'yinlarini fizika va matematika orqali dasturini batafsil tushunish imkonini beradi. Bu maqolada shu kabi masalalarga misollar bilan ko'rsatildi.

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ESTIMATE FOR THE UNBOUNDED SOLUTION OF A NONLINEAR PARABOLIC SYSTEM OF NONDIVERGENCE TYPE WITH CROSS-DIFFUSION

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Abstract: In this paper, studied the blow-up properties of solutions of nonlinear parabolic systems of non-divergent equations with a variable density. In solving the Cauchy problems for the equations of partial differential equations by the difference method important issue is the choose of the order of approximation with respect to the spatial coordinates and the choose of a function as an

initial approximation, as well as the search of an efficient algorithm for solving the systems of difference equations. We construct the difference scheme of high accuracy for nonlinear system of non-divergence form. Computational experiments confirming the high order accuracy difference scheme were conducted.

Keywords: *matematical model, asymptotic, cross-diffusion, nonlinear system, self-similar solution, Blow-up properties of solutions, non-divergent form.*

1. Introduction

In this paper, the qualitative blow-up properties of solutions to the following nonlinear system of non-divergence type parabolic equations with cross-diffusion are investigated

$$|x|^n \frac{\partial u_i}{\partial t} = u_{3-i}^{\alpha_i} \nabla \left(u_i^{m_i-1} |\nabla u_i^k|^{p-2} \nabla u_i \right) + |x|^n u_i^{\beta_i}, \quad (1)$$

$$u_i(0, x) = u_{0,i}(x) \geq 0, \quad x \in R^N, (i=1,2) \quad (2)$$

where, $\nabla(\cdot) = \text{grad}_x(\cdot)$, α_i, β_i, n, k - the numerical parameters, $p \geq 2$, $N \geq 1$ - the size of the space, the functions $u_i = u_i(t, x) \geq 0$, $x \in R^N$ are the solutions.

Using the comparison theorem, without solving the problem, we can estimate the solution from above and below, which is very important in studying the properties of nonlinear problems.

Nonlinear equations and systems of equations in non-divergence form are often used to describe various physical phenomena, such as diffusion processes for biological species, resistive diffusion phenomena in force-free magnetic fields, curve shortening flow, the spread of infectious diseases, and so on (see [3–6, 9]). System (1) is also referred to as a cross-diffusion system.

As shown in the works of many authors [1–8, nonlinear equations give rise to new nonlinear effects such as finite speed of propagation of disturbances (FSPD), spatial localization, blow-up, and others. These properties for cross-diffusion systems of non-divergence form have been studied in [7, 8]. In particular, models with cross-diffusion are of special importance in scientific research. The phenomenon of cross-diffusion expresses that the spatial distribution of one component depends on the concentration of another component. This process is widely used in modeling the interactions of biological populations, the dynamics of chemical reactions, and ecological systems.

One of the important problems for nonlinear parabolic equations is the study of the blow-up properties of solutions. The blow-up phenomenon refers to the situation where a solution grows without bound in a finite time. From a practical point of view, this process is often associated with phenomena such as rapid chemical reactions, uncontrolled temperature increase, or a sharp rise in the concentration of toxic substances. In technogenic systems, such processes can lead to the occurrence of emergency situations. For example, in the chemical industry, uncontrolled reactions of reactive substances may cause explosions or the release of toxic gases. Therefore, mathematical modeling of such processes and the identification of their critical regimes are of great scientific and practical importance.

We have investigated the qualitative properties of the solution to problem (1) based on self-similar analysis, as well as its numerical solutions using modern computer technologies, including the study of linearization methods to ensure convergence of the iterative process with subsequent visualization. To construct a self-similar system (1), a nonlinear splitting algorithm is proposed, for which the solution of system (1) is sought in the form

$$u_i(t, x) = \bar{u}_i(t) w_i(\tau, x), \quad w_i(\tau, x) = f_i(\xi) \quad (3)$$

$$\bar{u}_i(t) = (T - t)^{-\frac{1}{\beta_i-1}}, \quad \xi = \frac{r}{\tau^\alpha}, \quad r = |x|, \quad \alpha = \frac{1}{p+n}$$

$$\tau(t) = \begin{cases} \int (T-t)^{\frac{1-m_i-k(p-2)-\alpha_i}{\beta_i-1} + \frac{\alpha_i}{\beta_{3-i}-1}} dt, & \frac{1-m_i-k(p-2)-\alpha_i}{\beta_i-1} + \frac{\alpha_i}{\beta_{3-i}-1} + 1 \neq 0 \\ \text{Ln}(T-t), & \frac{1-m_i-k(p-2)-\alpha_i}{\beta_i-1} + \frac{\alpha_i}{\beta_{3-i}-1} + 1 = 0 \end{cases}$$

We obtain a self-similar system of equations

$$f_{3-i}^{\alpha_i} \xi^{1-N} \frac{d}{d\xi} \left(\xi^{N-1} f_i^{m_i-1} \left| \frac{df_i^k}{d\xi} \right|^{p-2} \frac{df_i}{d\xi} \right) + \varphi_i \xi^n \left(f_i^{\beta_i} - \frac{f_i}{\beta_i-1} \right) + \frac{1}{n+p} \xi^{n+1} \frac{df_i}{d\xi} = 0 \quad (4)$$

where $\varphi_i = \frac{\beta_i-1}{\beta_i-m_i-k(p-2)-\alpha_i}$, $(i=1,2)$

By applying the comparison method of solutions and the method of model (reference) equations to solve problem (4), one can obtain estimates for the solution of problems (1)–(2).

Let the following inequality $\gamma_i > 0$,

$$\gamma \gamma_{i+2} A_i^{k(p-2)+m_i} A_{3-i}^{k(p-2)+m_i} k^{p-2} |\gamma \gamma_i|^{p-2} = -\frac{1}{n+p}, \quad \varphi_i \left(A_i^{\beta_i-1} a^{\gamma_i \beta_i - \gamma_i} - \frac{1}{\beta_i-1} \right) - \frac{\gamma_i(N+n)}{(p+n)\gamma_{i+2}} \leq 0, \quad (i=1,2),$$

$$u_{i0}(0, x) \leq u_{i+}(0, x), \quad x \in \mathbb{R}^N.$$

Then the solution to problem (1)-(2) satisfies the following estimate

$$u_i(t, x) \leq u_{i+}(t, x) = A_i(T-t)^{-\frac{1}{\beta_i-1}} (a - \xi^\gamma)^{\gamma_i}, \quad (5)$$

where $a > 0$, $\gamma = \frac{p+n}{p-1}$, $\gamma_{i+2} = \gamma_i - \alpha_i \gamma_{3-i}$, $\gamma_i = \frac{m_{3-i} + (p-2)(m_{3-i}-1-\alpha_i) - \alpha_i - 1}{(m_{3-i}-1)(m_i - k\alpha_i(p-2) - 1) - \alpha_i \alpha_{3-i}}$

Theorem 1. $\gamma_i > 0$, $\varphi_i \left(A_i^{\beta_i-1} a^{\gamma_i \beta_i - \gamma_i} - \frac{1}{\beta_i-1} \right) - \frac{\gamma_i(N+n)}{(p+n)\gamma_{i+2}} \leq 0$, $(i=1,2)$ and $u_{0i}(0, x) \leq M_{0i}$

conditions must be met. Then for problem (1) - (2) the following estimates hold:

$$u_i(t, x) \leq A_i(T-t)^{-\frac{1}{\beta_i-1}} (a - \xi^\gamma)^{\gamma_i}, \quad T \leq \left(\frac{M_{0i} a^{-\gamma_i}}{A_i} \right)^{1-\beta_i}$$

here $M_{0i} = \max u_{0i}(x)$,

$$\xi = \frac{r}{\tau^\alpha} = \frac{|x|\sigma}{(T-t)^\sigma}, \quad a > 0, \quad \gamma = \frac{p+n}{p-1}, \quad \gamma_i = \frac{m_{3-i} + (p-2)(m_{3-i}-1-\alpha_i) - \alpha_i - 1}{(m_{3-i}-1)(m_i - k\alpha_i(p-2) - 1) - \alpha_i \alpha_{3-i}}$$

Proof. By condition of the theorem 3: $u_{0i}(0, x) \leq M_{0i}$,

$$u_i(t, x) \leq A_i(T-t)^{-\frac{1}{\beta_i-1}} (a - \xi^\gamma)^{\gamma_i}, \quad u_i(0, x) \leq A_i(T)^{-\frac{1}{\beta_i-1}} (a - \xi^\gamma)^{\gamma_i},$$

$$\gamma_i > 0, \quad \varphi_i \left(A_i^{\beta_i-1} a^{\gamma_i \beta_i - \gamma_i} - \frac{1}{\beta_i-1} \right) - \frac{\gamma_i(N+n)}{(p+n)\gamma_{i+2}} \leq 0, \quad (i=1,2),$$

We obtain

$$A_i T^{-\frac{1}{\beta_i-1}} a^{\gamma_i} \leq M_{0i} \\ T_i \leq \left(\frac{M_{0i} a^{-\gamma_i}}{A_i} \right)^{1-\beta_i},$$

If we denote $T = \min\{T_1, T_2\}$, we obtain the following:

$$T \leq \left(\frac{M_{0i} a^{-\gamma_i}}{A_i} \right)^{1-\beta_i}$$

Therefore, the proof of the theorem 1 completed.

In this paper, studied the blow-up properties of solutions of nonlinear parabolic systems of non-divergent equations with a variable density. The asymptotic behavior of self-similar solutions are analyzed for both the slow and fast diffusive regimes. It is shown that coefficients of the main

term of the asymptotic of solution satisfy some system of nonlinear algebraic equations. The found lower or upper solutions give us preliminary information about the exact solution.

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IKKI O‘LCHOVLI TRANSVERSAL IZOTROP JISMLAR UCHUN BOG‘LIQ TERMOELASTIK TENGLAMALARNI KOMPYUTERLI MODELLASHTIRISH

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Bizga ma’lumki jismga hech qanday kuch ta’sir qilmasa u o‘zining holatini o‘zgartirmaydi. Agarda jismga biror-bir kuch ta’sir etsa, u o‘zining holatini o‘zgartirishi mumkin ya’ni siqilishi, cho‘zilishi, siljishi yoki buralishi mumkin. Jismning deformatsiyalanish jarayoni undagi temperaturaning o‘zgarishiga va tashqi kuchlar ta’siriga xam bog‘liqdir. Umumiy holda temperatura deformatsiyaga va deformatsiya temperaturaning o‘zgarishiga ta’sir qilishi mumkin. Bunday jarayonlarni termoyelastiklik nazariyasi o‘rganadi.

Maqolada transversal izotrop jismlar uchun dinamik termoelestatik bog‘liq masala qaralgan. Bu chegaraviy masala giperbolik tipga tegishli xarakat tenglamasi va parabolik tipga tegishli issiqlik o‘tkazuvchanlik tenglamalaridan tashkil topgan bo‘lib, tenglamalarda ko‘chish funksiyasi va temperatura no‘malum sifatida qatnashadi. Qaralayotgan masala uchun oshkor va oshkormas tipdagi chekli ayirmali sxemalar qurilgan.

Quyida transversal izotrop jismlar uchun termoelestatik masalaning dinamik bog‘liqligining matematik modeli va bu modelni sonli yechish qaraladi. Transversal izotrop jismlar uchun bog‘liq dinamik masalaning ikki o‘lchovli holda harakat tenglamalari quyidagicha:

$$C_{1111} \frac{\partial^2 u}{\partial x^2} + (C_{1122} + C_{1212}) \frac{\partial^2 v}{\partial x \partial y} + C_{1212} \frac{\partial^2 u}{\partial y^2} - \beta_{11} \frac{\partial T}{\partial x} + X_1 = \rho \frac{\partial^2 u}{\partial t^2} \quad (1)$$

$$C_{1212} \frac{\partial^2 v}{\partial x^2} + (C_{1212} + C_{2211}) \frac{\partial^2 u}{\partial x \partial y} + C_{2222} \frac{\partial^2 v}{\partial y^2} - \beta_{22} \frac{\partial T}{\partial y} + X_2 = \rho \frac{\partial^2 v}{\partial t^2} \quad (2)$$

Transversal izotrop jismlar uchun issiqlik tarqalishi tenglamasi:

$$\lambda_{11} \frac{\partial^2 T}{\partial x^2} + \lambda_{22} \frac{\partial^2 T}{\partial y^2} - c_\varepsilon \frac{\partial T}{\partial t} - T(\beta_{11} \frac{\partial^2 u}{\partial x \partial t} + \beta_{22} \frac{\partial^2 v}{\partial y \partial t}) = 0 \quad (3)$$

bu tenglama uchun boshlang'ich shartlar quyidagicha

$$u(x, y, t)|_{t=0} = \varphi_1, \quad \frac{\partial u}{\partial t}|_{t=0} = \psi_1, \quad v(x, y, t)|_{t=0} = \varphi_2, \quad \frac{\partial v}{\partial t}|_{t=0} = \psi_2, \quad T(x, y, t)|_{t=0} = T_0 \quad (4)$$

va chegaraviy shartlar quyidagicha bo'ladi

$$u(x, y, t)|_{x=0} = u_0; \quad u(x, y, t)|_{x=\ell_1} = \bar{u}_0; \quad u(x, y, t)|_{y=0} = u'_0; \quad u(x, y, t)|_{y=\ell_2} = \bar{u}'_0 \\ v(x, y, t)|_{x=0} = v_0; \quad v(x, y, t)|_{x=\ell_1} = \bar{v}_0; \quad v(x, y, t)|_{y=0} = v'_0; \quad v(x, y, t)|_{y=\ell_2} = \bar{v}'_0 \quad (5)$$

$$T(x, y, t)|_{x=0} = T_1(t); \quad T(x, y, t)|_{x=\ell_1} = T_2(t); \quad T(x, y, t)|_{y=0} = T'_1(t); \quad T(x, y, t)|_{y=\ell_2} = T'_2(t)$$

tenglamalarni turli munosabatlarda ularning hosilalariga almashtiramiz. Bizning asosiy maqsadimiz masalani sonli yechish algoritmini qurishdan iborat. Buning uchun biz yuqorida hosil qilingan hususiy hosilali differensial tenglamalarni ayirmali tenglamalar bilan almashtiramiz.

Ikki o'lchovli holda x va y o'zgaruvchilar bo'yicha to'rtinchi quyidagicha aniqlaymiz:

$0 \leq x \leq l_1$, $0 \leq y \leq l_2$ ikkita parallel to'g'ri chiziqlar oilasini quramiz.

Bu masala quyidagi konstantalar orqali: $\beta_{11} = 0.6$, $\beta_{22} = 0.4$, $\alpha_{11} = 0.5$, $\alpha_{22} = 0.3$, $C_{1111} = 0.5$,

$C_{1212} = 0.92$, $C_{2222} = 0.73$, $C_{1122} = 0.56$, $C_{2211} = 0.56$, $l_1 = 1$, $l_2 = 1$, $h_1 = 0.1$, $h_2 = 0.1$, $C_e = 3.7$, $\tau = 0.01$,

$\rho = 0.6$, $T_0 = 10$

boshlang'ich shartlar

$$u(x, y, t)|_{t=0} = 0, \quad \frac{\partial u}{\partial t}|_{t=0} = 0, \quad v(x, y, t)|_{t=0} = 0, \quad \frac{\partial v}{\partial t}|_{t=0} = 0, \quad T(x, y, t)|_{t=0} = T_0 + T_0 \sin(\pi x_i) \cos(\pi y_j)$$

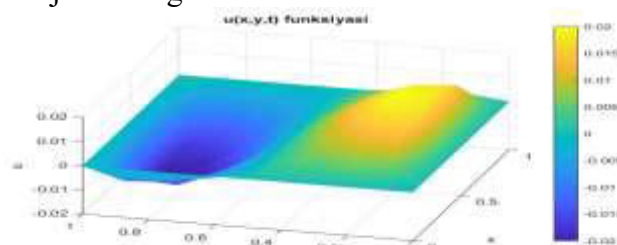
va chegaraviy shartlarda

$$u(x, y, t)|_{x=0} = 0; \quad u(x, y, t)|_{x=\ell_1} = 0; \quad u(x, y, t)|_{y=0} = 0; \quad u(x, y, t)|_{y=\ell_2} = 0$$

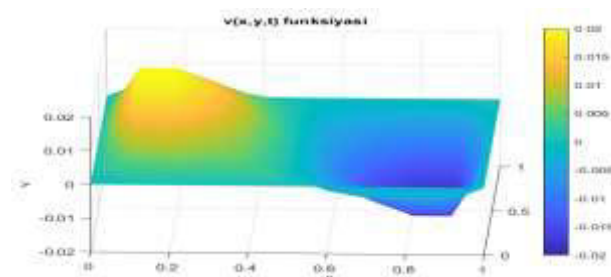
$$v(x, y, t)|_{x=0} = 0; \quad v(x, y, t)|_{x=\ell_1} = 0; \quad v(x, y, t)|_{y=0} = 0; \quad v(x, y, t)|_{y=\ell_2} = 0$$

$$T(x, y, t)|_{x=0} = T_0; \quad T(x, y, t)|_{x=\ell_1} = T_0; \quad T(x, y, t)|_{y=0} = T_0; \quad T(x, y, t)|_{y=\ell_2} = T_0$$

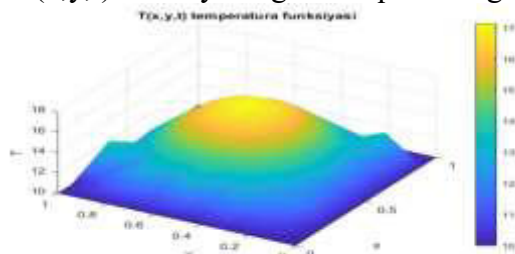
berilgan va bu shartlar asosida To'rtlar usulida sonli yechilgan. MAPLE 7.0 matematik paketi yordamida quyidagi vizual natijalar olingan.



1-rasm. $u(x, y, t)$ funksiyaning $n=10$ qatlamdagi qiymatlari



2-rasm. $v(x,y,t)$ funksiyaning $n=10$ qatlamdagi qiymatlari



3-rasm. $T(x,y,t)$ funksiyaning $n=10$ qatlamdagi qiymatlari quyidagicha

Xulosa o'rnida shuni aytish joizki, maqolada transversal izotrop jismlar uchun bog'liq termoelastik tenglamalarning sonli modeli ishlab chiqildi va chekli ayirmali usullar asosida yechim olindi. Hisoblash natijalari temperatura hamda deformatsiya maydonlarining o'zaro bog'liqligini tasdiqlab, modelning amaliy samaradorligini ko'rsatdi.

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ANALYSIS OF DIFFERENCE SCHEMES FOR ANOMALOUS FILTRATION EQUATIONS

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Abstract. In this work, the problem of anomalous fluid filtration will be focused. Difference schemes were used to develop mathematical models of anomalous filtration.

Keywords. Fractal differential equations, anomalous filtration, difference scheme, numerical solutions.

The Caputo fractional derivate and Riemann-Liouville fractional derivate methods will be demonstrated. The Caputo fractional derivate will be solved by L1 scheme. Riemann-Liouville fractional derivate wil be discretized using the Grunwald-Letnikov scheme.

$$\mu\beta^* \frac{\partial^\alpha u}{\partial t^\alpha} = k \frac{\partial^2 u}{\partial x^2} \quad (1)$$

Where u — is the pressure, t — is the time, μ — is the dynamic viscosity, k — is the fractal permeability β^* — is the elastic capability coeffitsient of the medium.

The given formula (1) was approximated by Grunwald-Letnikov scheme as follows:

$$\mu\beta^* \frac{1}{\tau^\alpha} \left(\sum_{k=1}^{j+1} (-1)^k \binom{\alpha}{k} u_i^{j+1-k} + u_i^{j+1} \right) = k \frac{u_{i+1}^{j+1} - 2u_i^{j+1} + u_{i-1}^{j+1}}{h^2} \quad (2)$$

$i = \overline{1, N_1 - 1}, j = \overline{0, N_2 - 1}$

The formula (2) shown above can be written in canonical form as follows:

$$Au_{i+1}^{j+1} - Bu_i^{j+1} + Cu_{i-1}^{j+1} = -F_i^j \quad (3)$$

Where

$$A = \frac{k}{h^2}, B = \frac{2k}{h^2} + \mu\beta^* \frac{1}{\tau^\alpha}, C = \frac{k}{h^2}, F_i^j = \mu\beta^* \frac{1}{\tau^\alpha} \left(\sum_{k=1}^{j+1} (-1)^k \binom{\alpha}{k} u_i^{j+1-k} \right)$$

The indicated system (3) is solved by Thomas algorithm.

$$u_i^{j+1} = \alpha_{i+1} u_{i+1}^{j+1} + \beta_{i+1} \quad (4)$$

Where $\alpha_{i+1}, \beta_{i+1}$ – coefficients.

The presented (1) formula is reduced to discrete by L1 scheme.

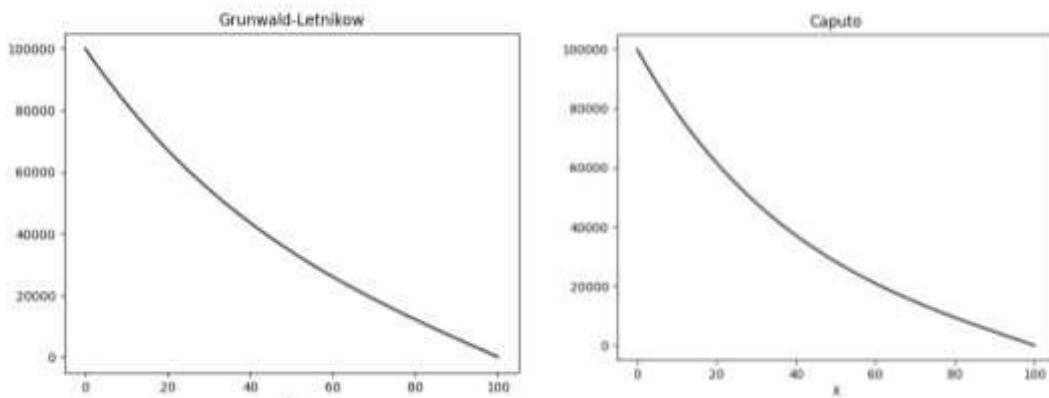
$$\begin{aligned} \mu\beta^* \frac{\tau^{1-\alpha}}{\Gamma(2-\alpha)} \left(\sum_{k=1}^{j-1} \frac{u_i^{k+1} - u_i^k}{\tau} \cdot ((j-k-1)^{1-\alpha} - (j-k)^{1-\alpha}) + \frac{u_i^{j+1} - u_i^j}{\tau} \right) = \\ = k \frac{u_{i+1}^{j+1} - 2u_i^{j+1} + u_{i-1}^{j+1}}{h^2} \end{aligned} \quad (5)$$

Using (3), we obtain:

$$\begin{aligned} A = \frac{k}{h^2}, B = \frac{2k}{h^2} + \mu\beta^* \frac{1}{\tau^\alpha \Gamma(2-\alpha)}, C = \frac{k}{h^2}, \\ F_i^j = u_i^j - \mu\beta^* \frac{1}{\tau^\alpha \Gamma(2-\alpha)} \left(\sum_{k=1}^{j-1} \frac{u_i^{k+1} - u_i^k}{\tau} \cdot ((j-k-1)^{1-\alpha} - (j-k)^{1-\alpha}) \right) \end{aligned}$$

Where Γ – gamma function.

The figure 1 shows the pressure distribution over time t for the Caputo and Riemann-Liouville models:



Conclusion

Consequently, Riemann-Liouville tends to pure mathematical theory, whereas Caputo is more suitable for difference scheme.

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NUMERICAL MODELLING OF STONELEY WAVES IN A FLUID-SATURATED POROELASTIC HALF-SPACE

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Abstract. This study presents a numerical investigation of Stoneley wave propagation at a planar interface between an acoustic fluid and a fluid-saturated porous half-space governed by Biot's fully coupled displacement–pressure (u – p) equations. A staggered-grid finite-difference (SGFD) scheme is developed and validated against the analytically derived Stoneley wave secular equation. Dispersion curves and attenuation spectra are computed over 10 Hz – 50 kHz. Parametric studies quantify the effects of porosity ($\phi = 0.10$ – 0.40), intrinsic permeability ($\kappa = 10^{-15}$ – 10^{-12} m²), and frequency on phase velocity, attenuation, and penetration depth. Phase velocity decreases from 1449 m/s to 1310 m/s (10 Hz–10 kHz), confirming anomalous dispersion with $< 1.2\%$ deviation from the Norris (1989) analytical solution.

Keywords: Stoneley waves, Biot theory, porous media, finite-difference method, dispersion, permeability.

1. Introduction

Stoneley waves propagate along the interface between a fluid-saturated porous formation and a bounding acoustic fluid, serving as the primary seismic indicator of formation permeability in borehole acoustic logging. Biot (1956) established the governing poroelastic equations, extending the classical elastic half-space formulation [6] to the fully coupled fluid-solid case. Rosenbaum (1974) derived the Stoneley wave characteristic equation for cylindrical borehole geometry. The present work considers the simpler planar-interface case. Norris (1989) obtained low-frequency analytical approximations for phase velocity and attenuation at planar interfaces. Despite this analytical foundation, a systematic numerical study spanning the full Biot frequency range — from the viscous regime ($\omega \ll \omega_c$) through the inertial regime ($\omega \gg \omega_c$) — with comprehensive parameter sensitivity analysis has not been systematically addressed. This work addresses that gap.

2. Theoretical Model and Key Formulas

The porous half-space ($z \geq 0$) is governed by the Biot u – p equations. Solid displacement u and pore pressure p satisfy:

$$\nabla \sigma - \alpha \nabla p = \rho \frac{\partial^2 \mathbf{u}}{\partial t^2} + \rho_f \frac{\partial^2 \mathbf{w}}{\partial t^2} \quad (1)$$

$$-\nabla p - \left(\frac{\eta}{\kappa}\right) \frac{\partial \mathbf{w}}{\partial t} = \rho_f \frac{\partial^2 \mathbf{u}}{\partial t^2} + \tilde{\rho} \frac{\partial^2 \mathbf{w}}{\partial t^2} \quad (2)$$

$$\frac{\partial p}{\partial t} = -M \left(\alpha \frac{\nabla \partial \mathbf{u}}{\partial t} + \frac{\nabla \partial \mathbf{w}}{\partial t} \right) \quad (3)$$

where $\mathbf{w} = \phi(\mathbf{U} - \mathbf{u})$ is the relative fluid displacement, $\tilde{\rho} = \frac{\rho_f r}{\phi} + \frac{\eta}{i\omega\kappa}$ is the dynamic fluid density, and $\alpha = 1 - \frac{K_d}{K_s}$, $M^{-1} = \frac{\alpha - \phi}{K_s} + \frac{\phi}{K_f}$ are the Biot–Willis coefficient and storage modulus (Gassmann 1951). The open-pore boundary conditions at $z = 0$ are:

$$\sigma_{zz}^{\text{total}} = -p_f, \quad \sigma_{xz} = 0, \quad u_z^{(\text{solid})} = u_z^{(\text{fluid})}, \quad p = p_f \quad (4)$$

The Stoneley wavenumber $K(\omega)$ is found from the 2×2 secular equation obtained by eliminating two variables from the 4×4 boundary-condition matrix:

$$F(K, \omega) = E_{11}E_{22} - E_{12}E_{21} = 0 \quad (5)$$

where the matrix entries E_{ij} depend on the Biot P_1 , P_2 , and S wavenumbers, computed from the quadratic:

$$MHk^4 - \omega^2(\rho M + R\tilde{\rho} - 2\alpha M\rho_f)k^2 + \omega^4(\rho\tilde{\rho} - \rho_f^2) = 0 \quad (6)$$

$$(H = K_d + \frac{4G}{3}, P = K_u + \frac{4G}{3}) \text{ Phase velocity } V_{St} = \frac{\omega}{\text{Re}(K)} \text{ and attenuation } \alpha = \text{Im}(K).$$

For numerical simulation, (1)–(3) are discretised on a staggered Cartesian grid with second-order

spatial and temporal differences, following Zeng et al. (2001). The stability condition is $\Delta t \leq \frac{0.5 \Delta x}{\sqrt{2} \cdot c_{P1}}$ Convolutional PML layers suppress boundary reflections.

3. Results

Figure 1 shows the reference model dispersion curves (water-saturated sandstone: $\phi = 0.25$, $\kappa = 10^{-13} \text{ m}^2$). Phase velocity decreases from 1449 m/s (10 Hz) to 1310 m/s (10 kHz), demonstrating anomalous dispersion; agreement with the Norris (1989) analytical approximation is within 1.2% below 1 kHz. Attenuation follows a $f^{1/2}$ law in the viscous regime and saturates near the Biot characteristic frequency $f_c = \frac{\eta\phi}{2\pi\kappa\rho_f} \approx 398 \text{ kHz}$.

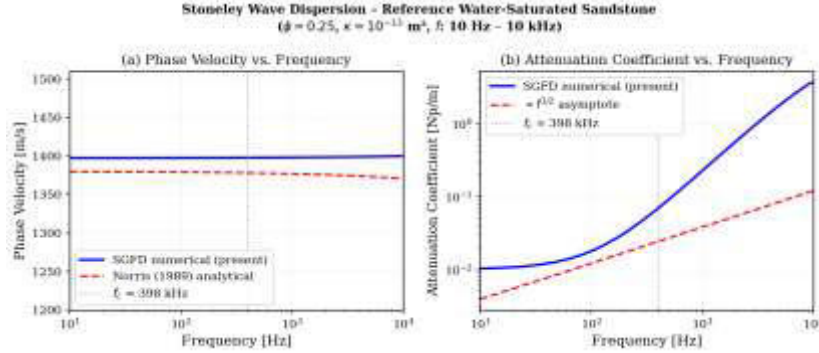


Figure 1. (a) Phase velocity and (b) attenuation vs. frequency for the reference model. Solid blue: SGFD numerical solution; dashed red: Norris (1989) analytical approximation. Dotted grey: Biot characteristic frequency $f_c \approx 398 \text{ kHz}$.

Permeability sensitivity. Attenuation is most sensitive to permeability in the 100 Hz – 10 kHz window; outside this band, viscous (low-f) and inertial (high-f) forces suppress relative fluid motion and attenuate the permeability signal. Phase velocity is insensitive to κ across all frequencies studied.

Porosity effect (Table 1, at 1 kHz). Increasing ϕ from 0.10 to 0.40 reduces V_{St} by 9.5%, increases attenuation by $\times 17.7$, and reduces the 1/e penetration depth by 61%.

ϕ	$V_{St} \text{ (m/s)}$	att(Np/m)	dp = 1/e penetration depth
0.10	1448	0.011	1.35
0.25	1409	0.068	0.78
0.40	1310	0.195	0.52

Table 1. Stoneley wave parameters at 1 kHz vs. porosity. $\kappa = 10^{-13} \text{ m}^2$ throughout.

4. Conclusion

A validated SGFD scheme for the Biot u - p system at a permeable fluid/porous interface reproduces Stoneley wave dispersion to within 1.2% of the secular equation across 10 Hz – 50 kHz. Anomalous dispersion is observed across all lithologies examined ($\phi = 0.10$ – 0.40 , $\kappa = 10^{-15}$ – 10^{-12} m^2). Attenuation is permeability-diagnostic only in the 100 Hz – 10 kHz band, defining the optimal window for acoustic log inversion. The 1/e penetration depth decreases from 2.8 m (100 Hz) to 0.4 m (5 kHz), enabling depth-radial profiling of formation properties through multi-frequency measurements.

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THE CAUCHY PROBLEM FOR THE BEAM VIBRATION EQUATION WITH THE TIME-FRACTIONAL RIEMANN-LIOUVILLE DERIVATIVE

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In recent years, the theory of fractional differential equations has become one of the most actively developing areas of mathematics. This theory generalizes the classical concept of integer-order derivatives and makes it possible to take into account the memory and nonlocal properties of the modeled processes. In this work, the Cauchy problem for the beam oscillation equation involving the Riemann--Liouville operator with respect to time is investigated.

In the domain

$$\Omega = \{(x, t) : x \in R, t > 0\},$$

consider the fractional differential equation

$${}^{RL}D_{0t}^{\alpha}V(x, t) + \frac{\partial^4 V(x, t)}{\partial x^4} = 0 \quad (1)$$

with the initial conditions

$$\lim_{t \rightarrow 0} I_{0t}^{2-\alpha} V(x, t) = \varphi(x), \quad \lim_{t \rightarrow 0} {}^{RL}D_{0t}^{\alpha-1} V(x, t) = 0 \quad (2)$$

Find a solution $V(x, t) \in M$ satisfying these conditions, where ${}^{RL}D_{0t}^{\alpha}$ is the Riemann--Liouville fractional derivative defined by:

$${}^{RL}D_{0t}^{\alpha} f(x, t) = \frac{1}{\Gamma(2-\alpha)} \frac{\partial^2}{\partial t^2} \int_0^t (t-\tau)^{1-\alpha} f(x, \tau) d\tau,$$

$1 < \alpha < 2$, $\varphi(x)$ is a given sufficiently smooth function, and M is the space of functions such that

$$I_{0t}^{2-\alpha} V(x, t), {}^{RL}D_{0t}^{\alpha-1} V(x, t) \in C(\bar{\Omega}), \quad {}^{RL}D_{0t}^{\alpha} V(x, t) \in C(\Omega), \quad V(x, t) \in C_x^2(\bar{\Omega}) \cap C_x^4(\Omega).$$

Theorem. In order for the function $V(x, t) \in M$ to be a solution of problem (1)--(2), it is necessary and sufficient that the function

$$I_{0t}^{1-\alpha/2} U(x, t) = I_{0t}^{2-\alpha} V(x, t) + i \int_0^t V_{xx}(x, s) ds \quad (3)$$

be a solution of the equation

$${}^{RL}D_{0t}^{\alpha/2} U(x, t) - i U_{xx}(x, t) = 0, \quad (x, t) \in \Omega \quad (4)$$

satisfying the initial condition

$$\lim_{t \rightarrow 0} I_{0t}^{1-\alpha/2} U(x, t) = \varphi(x) \quad (5)$$

where i is the imaginary unit.

The following result follows from this theorem.

Corollary 1. Suppose that $U \in M$ is a solution of problem (4)--(5), where $\varphi(x)$ is a real-valued function. Then the function $V(x, t) = \operatorname{Re} U(x, t)$ is a solution of problem (1)--(2). Where $\operatorname{Re} U(x, t)$ denotes the real part of the function $U(x, t)$.

To solve problem (1)-(2), we use Corollary 1. Then we arrive at the problem of finding a solution of the one-dimensional time-fractional Schrödinger equation

$${}^{RL}D_{0t}^{\alpha/2} U(x, t) - iU_{xx}(x, t) = 0$$

satisfying the initial condition (5). The solution of this problem was obtained in [1] in the

following form: $U(x, t) = \int_{-\infty}^{\infty} \varphi(\xi) G_{\alpha}(x - \xi, t) d\xi$,

$$\text{where } G_{\alpha}(x - \xi, t) = \frac{1}{\sqrt{2\pi}} t^{\frac{\alpha}{2}-1} \int_{-\infty}^{\infty} e^{ik(x-\xi)} E_{\frac{\alpha}{2}, \frac{\alpha}{2}} \left(-iz^2 t^{\frac{\alpha}{2}} \right) dz = \frac{1}{2} \frac{1}{\sqrt{i}} t^{\frac{\alpha}{4}-1} W_{-\frac{\alpha}{4}, \frac{\alpha}{4}} \left(-\frac{|x-\xi|}{\sqrt{i} t^{\frac{\alpha}{4}}} \right).$$

From Corollary 1, the solution of problem (1)--(2) is obtained in the form:

$$V(x, t) = \int_{-\infty}^{\infty} \varphi(\xi) G_{1\alpha}(x - \xi, t) d\xi,$$

where

$$G_{1\alpha}(x - \xi, t) = \sqrt{\frac{2}{\pi}} \int_0^{\infty} \cos(x - \xi) E_{\alpha, \frac{\alpha}{2}}(-z^4 t^{\alpha}) dz,$$

$$G_{1\alpha} = \frac{1}{2} t^{\frac{\alpha}{4}-1} \sum_{n=0}^{\infty} \frac{\left(-\frac{|x-\xi|}{t^{\frac{\alpha}{4}}} \right)^n \cos\left(\frac{\pi}{4} n + \frac{\pi}{4} \right)}{n! \Gamma\left(-\frac{\alpha}{4} n - \frac{\alpha}{4} \right)}.$$

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THE PRINCIPLE OF DETERMINING THE OPTIMAL SEQUENCE OF ALGORITHMS FOR CLASSES OF OPTIMIZATION PROBLEMS

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Annotation. This article discusses the problem of selecting optimal algorithms for solving mathematical programming problems based on the analysis of convergence rate functions $\varepsilon(K)$, where ε denotes the achieved accuracy and K represents the number of iterations. The study examines the comparative efficiency of stochastic and regular optimization algorithms through graphical analysis of convergence curves. A methodology for determining the most effective algorithm and constructing optimal sequences of algorithms is proposed by analyzing the intersection points of convergence functions and their derivatives. The paper also considers the creation of libraries of parameterized test functions for algorithm evaluation and emphasizes the importance of model identification, stochastic approximation, and normalization procedures when transferring optimized algorithms from test problems to real-world applications. The proposed

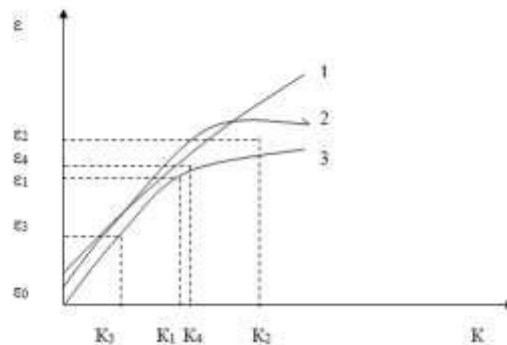
approach enables adaptive selection of optimization methods with maximum convergence speed and minimal computational cost.

Keywords: mathematical programming, optimization algorithms, convergence rate, stochastic search, test functions, model identification, algorithm sequence.

As is known [1, 2, 3, 9], different algorithms have different rates of convergence when solving mathematical programming problems. The difference in their convergence rates is expressed not only in absolute figures, but also in the form of the graph $\varepsilon(K)$, where ε is the achieved accuracy (let's say, the radius ε is the neighborhood around the exact solution X^*), K is the number of iterations. Similar graphs can be obtained when testing different algorithms. Thus, graphs of $\varepsilon(K)$ as applied to random search algorithms and some regular ones are given in the works of L.A. Rastrigin [6, 7, 8], where, in particular, the improvement in convergence of random search compared to the gradient method with an increase in the optimized parameters is illustrated.

Thus, using the $\varepsilon(K)$ dependencies obtained experimentally for various algorithms on various models with different values of n (the number of parameters being optimized), we can, by storing this data in computer memory, uniquely select an algorithm based on its optimality to solve a problem with a given accuracy ε (assuming the model is close to the test models considered).

Suppose that for a certain test problem, the $\varepsilon(K)$ curves for three different algorithms have



the form (Fig. 1).

Fig.1.

As can be seen from Figure 1, in the $\varepsilon_0\varepsilon_1$ region, algorithm №3 is more efficient, then in the $\varepsilon_1\varepsilon_2$ zone, algorithm №2 is more efficient, and then №1. Knowing the intersection points K_1 and K_2 of the $\varepsilon_i(K)$ curves, we can, with a minimum of information (model number, number of variables, algorithm numbers, and intersection points), determine the optimal algorithm for each given accuracy.

This is a fairly simple way to determine an algorithm from an optimality standpoint. However, to use this algorithm selection scheme, the initial information about the problem may not be sufficient. Therefore, it is necessary to analyze the model for its most complete identification. This requires the use of statistical analysis and pattern recognition methods.

Using $\varepsilon(K)$ graphs constructed for various models and algorithms, we can determine the optimal sequence of algorithms with the maximum convergence rate. To do this, it is necessary to examine the curves, i.e., the first derivatives of $\varepsilon'(K)$, and determine their intersection points. When solving a problem with a given $\varepsilon'(K)$, it is advisable to select at each stage of the search the algorithm that is higher than the others; at the points K_3 and K_4 of intersection of the curves, you should switch to a new algorithm (see Fig. 2)

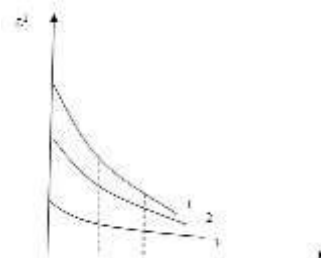


Fig. 2.

As we can see, a sequence of algorithms has a higher convergence rate than any single algorithm.

Thus, with data on the $\varepsilon(K)$ curves in computer memory, it is possible to determine not only the optimal algorithm for a given class of problems, but also their sequence.

The $\varepsilon(K)$ curves are constructed based on the results of solving test problems for only tuned algorithms, i.e., those that have undergone the optimization stage.

For testing algorithms, there are many test models, such as those described in [4, 5]. They differ not only in the type of the objective function, but often the same function, with different values of the constants, has different minima. Therefore, to create a library of test functions, they must be parameterized, i.e., all the parameters whose variations can be used to achieve a particular model type must be identified. Test functions found in the literature are proposed for specific parameter values, often selected to best showcase the author's proposed algorithm. When it comes to a library of test problems for testing a package of algorithms, it is required to provide the maximum number of models with minimal memory consumption.

After determining optimal algorithms (or their sequence) on test problems, they can be applied to real models. This requires solving the following problems:

1. Nondimensionalizing the model;
2. Reducing the domain of existence of its solutions to the test models;
3. Stochastic approximation of the model;
4. Model identification.

The first two problems are solved quite simply. Nondimensionalizing the model can be done as follows.:

$$\bar{F} = \frac{F(X)}{F(X_{\max})} \text{ или } \bar{F} = \frac{F(X)}{F(X_{\min})},$$

where $F(X)$ is the current value of the objective function, $F(X_{\max})$ or $F(X_{\min})$ is the value of F at the maximum and minimum values of the parameters. The reduction of the domains to the specified dimensions is performed using a linear transformation of the variables. For example: if the parameter varies within the range $a_i \leq x_i \leq b_i$, then to reduce it to the interval $[0, 1]$, you should enter

$$\bar{x}_i = \frac{x - a_i}{b_i - a_i}, \text{ then } 0 \leq \bar{x}_i \leq 1.$$

The third task involves approximating the model using a system of analytical functions after conducting a series of statistical experiments. Based on the results of these experiments, a table of the distribution of the target function values is compiled, which is approximated using analytical functions. Approximation can be performed analytically (without searching) by solving the corresponding system of equations (which can be too difficult) or using search methods, solving the problem of minimizing residuals. Here, an optimization problem also arises, which is solved using the algorithms built into the system.

The problem of identification, or model recognition, involves assigning the model to a particular class of test functions. This problem can be solved using pattern recognition methods as well as search algorithms. The problems of approximation and model identification can be combined if the test functions built into the system are used as approximating functions. By solving the residual minimization problem one by one by determining the values of the test function constants and comparing the resulting residuals, the model can be assigned to the test function with the minimal residual. If a certain proximity standard for the model and test functions is defined, then if a residual no greater than this proximity standard is obtained at any stage, the model identification can be completed.

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G‘OVAK MUHITDA MODDA KO‘CHISHINING KO‘P BOSQICHLI KINETIKA ASOSIDAGI GIBRID MODEL

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Annotatsiya. Ushbu ishda g‘ovak muhitda modda ko‘chishining gibrid modeli ko‘p bosqichli kinetika asosida tuzilgan va sonli tadqiq etilgan.

Filtr yuzasida keyk qatlami hosil qilish bilan suspenziyalar sizishi (cake filtration) va zarrachalarning cho‘kish muhit ichida hosil bo‘ladigan g‘ovak muhitlarda birjinslimas suyuqliklarning sizishi (deep bed filtration) kombinatsiyalangan jarayonini o‘rganish uchun bizga zarrachalarning filtr muhiti ichida va yuzasida ko‘chishi va cho‘kishini tavsiflovchi adekvat modellar kerak. Ushbu ishda keyk sizish va chuqur qatlamli sizishning kombinatsiyalangan jarayoni uchun matematik modellar taqdim etilgan, uning sonli tahlilini keltirilgan. Ushbu birlashtirilgan sizish jarayonlariga mos keladigan matematik modellar gibrid modellar deb ataladi [1-3].

Dastlabki vaqt momentida g‘ovakligi m_2 va uzunligi s_0 ga teng bir jinsli g‘ovak muhitni qaraymiz, u toza ya’ni tarkibida muallaq zarrachalar mavjud bo‘lmagan suyuqlik bilan to‘yintirilgan deb qaraymiz. $x=0$ nuqtada, $t>0$ dan boshlab qatlamga tarkibida konsentratsiyasi c_0 ($c_0 = c_{10} + c_{20}$) bo‘lgan ikki xil o‘lchamdagi qattiq zarrachalarni saqlovchi bir jinslimas suyuqlik $v(t) = v = \text{const}$ tezlik bilan kirib keladi. Jarayon davomida suspenziyadagi yirik zarrachalar g‘ovak muhit yuzasida ushlanib qolib, keyk qatlamini hosil qiladi. Mayda zarrachalar esa g‘ovak muhit ichiga kirib boradi va chuqur qatlamli filtratsiya jarayonida ishtirok etadi. Bundan tashqari, keyk qatlam ichida ham mayda zarrachalarning cho‘kib qolishi kuzatiladi.

G‘ovak muhit ($x \in [0, s_0]$) uchun chuqur qatlamli filtrlash tenglamalari

$$m_2 \frac{\partial c_2}{\partial t} + v \frac{\partial c_2}{\partial x} + \frac{\partial \sigma_2}{\partial t} = D_2 \frac{\partial^2 c_2}{\partial x^2}, \quad x \in [0, s_0], \quad (1)$$

$$\frac{\partial \sigma_2}{\partial t} = \begin{cases} k_{2r} v \sigma_2, & 0 < \sigma_2 \leq \sigma_{2r}, \\ k_{2a} v c_2 - k_{2d} \sigma_2, & \sigma_{2r} < \sigma_2 < \sigma_{20}, \\ 0, & \sigma_2 = \sigma_{20}, \end{cases} \quad x \in [0, s_0], \quad (2)$$

bu yerda c_2 – suspenziya tarkibidagi kichkina zarachalar konsentratsiya, v – sizish tezligi, m_2 – g‘ovak muhitning g‘ovaklik koeffitsienti, σ_2 – g‘ovak muhitda hosil bo‘lgan cho‘kma konsentratsiyasi, D_2 – g‘ovak muhitdagi diffuziya koeffitsienti, bu yerda σ_{20} – filtrning umumiy sig‘imi, σ_{2r} – σ_2 ning yuklanish chegarasi xarakterlovchi parametr, k_{2r} – g‘ovak muhitda “yuklanish” ta’siri bilan bog‘liq kinetik koeffitsient, k_{2a} – g‘ovak muhitda qattiq zarrachalarning o‘tirib qolishini harakterlovchi koeffitsient, k_{2d} – g‘ovak muhitda qattiq zarrachalarning qayta oqimga qo‘shilishni harakterlovchi koeffitsient.

Keyk qatlam o‘shishini xarakterlovchi tenglama

$$\frac{ds}{dt} = \frac{c_1 v}{(1-m_1)}, \quad x = s(t), \quad (3)$$

bu yerda c_1 – suspenziya tarkibidagi katta zarachalar konsentratsiya, $s(t)$ – keyk qatlam qalinligi, m_1 – keyk qatlam g‘ovaklik koeffitsienti.

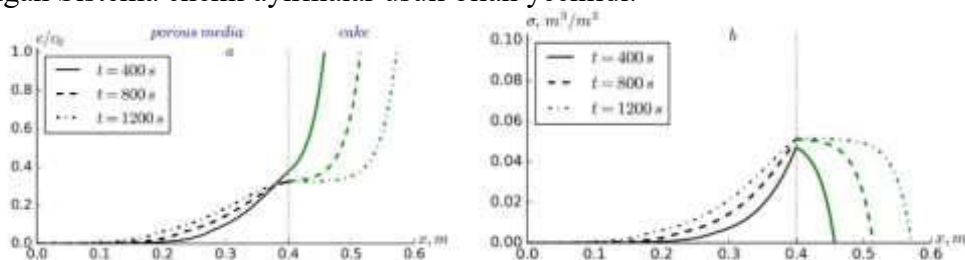
Keyk qatlamda ($x \in [0, s_0]$) uchun chuqur qatlamli filtlash tenglamalari

$$m_1 \frac{\partial c_2}{\partial t} + v \frac{\partial c_2}{\partial t} + \frac{\partial \sigma_1}{\partial t} = D_1 \frac{\partial^2 c_2}{\partial x^2}, \quad x \in [s_0, s(t)], \quad (4)$$

$$\frac{\partial \sigma_1}{\partial t} = \begin{cases} k_{1r} v \sigma_1, & 0 < \sigma_1 \leq \sigma_{1r}, \\ k_{1a} v c_2 - k_{1d} \sigma_1, & \sigma_{1r} < \sigma_1 < \sigma_{10}, \quad x \in [s_0, s(t)], \\ 0, & \sigma_1 = \sigma_{10}, \end{cases} \quad (5)$$

bu yerda σ_1 – keyk qatlamda hosil bo‘lgan cho‘kma konsentratsiyasi, D_1 – keyk qatlamdagi diffuziya koeffitsienti, bu yerda σ_{10} – keyk qatlamda hosil bo‘lishi mumkin bo‘lgan cho‘kmaning maksimal qiymati, σ_{1r} – σ_1 ning yuklanish chegarasi xarakterlovchi parametr, k_{1r} – keyk qatlamdada “yuklanish” ta’siri bilan bog‘liq kinetik koeffitsient, k_{1a} – keyk qatlamdada qattiq zarrachalarning o‘tirib qolishini harakterlovchi koeffitsient, k_{1d} – keyk qatlamdada qattiq zarrachalarning qayta oqimga qo‘shilishni harakterlovchi koeffitsient.

Hosil bo‘lgan Sistema chekli ayirmalar usuli bilan yechildi.



1-rasm. c/c_0 (a), σ (b) lar qiymatlarning vaqtning turli qiymatlarida o‘zgarish profillari.

(qora chiziqlar g‘ovak muhitga, yashil chiziqlar keyk qatlamga mos keladi, ko‘ndalang qizil shtirx chiziq keyk qatlam va g‘ovak muhit chegarasini ifodalaydi)

Grafiklarda keyk qatlam va g‘ovak muhitda muallaq zarrachalar konsentratsiyasi hamda cho‘kma konsentatsiya aks ettirilgan bo‘lib, g‘ovak muhitdagi konsentratsiyalar qora rangda, keyk qatlamdagilari esa yashil rangda chizilgan.

Natijalar tahlili shuni ko‘rsatadiki, vaqt o‘tishi bilan keyk qatlam o‘sib boradi, unga mutanosib ravishda ham keyk qatlamda, ham g‘ovak muhitda muallaq zarrachalar konsentratsiyasi va cho‘kma konsentatsiya ortib boradi.

Keyk qatlam ortib borishi bilan, kiruvchi oqim fronti ham dastlabki $s_0 = 0,4$ nuqtadan asta sekin uzoqlashib boradi, xususan, $t = 400 s$ da $s(t) \approx 0,457 m$ nuqttagacha, $t = 800 s$ da $s(t) \approx 0,514 m$ gacha va $t = 1200 s$ da $s(t) \approx 0,571 m$ nuqttagacha yetib boradi (a-rasm). Keyk

qatlamda muallaq zarrachalar kontratsiyasining tarqalishida vaqt o'tishi bilan front surilishi natijasida fiksirlangan nuqtalarda kamayish kuzatiladi.

Bu xususiyat g'ovak muhitning faqat $s_0 = 0,4$ nuqtaga yaqin nuqtalardagina saqlanadi, undan uzoqlashganda esa aksincha, vaqt ortishi bilan konsentratsiya oshishini kuzatish mumkin. Cho'kma konsentratsiyasida esa ham g'ovak muhitda, ham keyk qatlamda vaqt o'tishi bilan faqat o'sish kuzatiladi (1b-rasm).

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NEFTNI SUV BILAN SURIB CHIQUARISH JARAYONIDA OLISH MUMKIN BO'LGAN NEFT HAJMINI ANIQLASH

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Annotatsiya. Mazkur maqolada neft konlarida suv haydash asosidagi ikkilamchi qazib olish jarayonini matematik modellashirish masalasi ko'rib chiqilgan. Ikki fazali filtratsiya jarayonini tavsiflash uchun Bakley–Leverett modelidan foydalanilgan. Model tenglamasini sonli yechish asosida qatlamdagi suv fazasi to'yinganligi taqsimotini hamda qazib olinishi mumkin bo'lgan neft hajmini hisoblash algoritmlari ishlab chiqilgan. Hisoblashlarda chekli ayirmali sxema qo'llanilgan bo'lib, natijada suv frontining harakati dinamikasi va qazib olinishi mumkin bo'lgan neft hajmi hisoblangan.

Kirish. Hozirgi kunda neft konlarida mavjud zaxiralarning katta qismini qazib olish murakkab texnologik masalalardan biri hisoblanadi. Qatlam bosimining kamayishi natijasida tabiiy oqim sustlashadi va qo'shimcha ta'sir usullarini qo'llash zarurati yuzaga keladi. Shunday usullardan biri suv bilan surib chiqarish asosidagi ikkilamchi neftni qazib olish texnologiyasi hisoblanadi. Suv bilan surib chiqarish jarayonida suv maxsus quduqlar orqali qatlamga yuboriladi va u neftni surib chiqarib, qazib chiqaruvchi quduqlar tomon harakatlantiradi. Ushbu jarayonning samaradorligini oldindan baholash uchun matematik modellar va kompyuterda hisoblash usullaridan foydalanish muhim ahamiyatga ega.

Ikki fazali filtratsiya jarayonlarini tavsiflashda qo'llaniladigan matematik modellardan biri Bakley–Leverett modelidir. Mazkur model suv va neft fazalarining g'ovak muhitdagi harakatini tavsiflaydi hamda surib chiqaruvchi suv frontining dinamikasini aniqlash imkonini beradi.

Matematik model. Ikki fazali filtratsiya uchun asosiy tenglama quyidagi ko'rinishga ega:

$$m \cdot \frac{\partial S}{\partial t} + W \cdot \frac{\partial \varphi(S)}{\partial x} = 0 \quad (1)$$

bu yerda m – neftli muhitning g'ovakligi, x - fazoviy o'zgaruvchi. $\varphi'(S) \geq 0$, W surib chiqarayotgan fazaning hajmiy tezligi. Q_h haydovchi quduq $x=0$ nuqtada, Q_q qazib oluvchi

quduq esa $x = L$ nuqtada joylashgan deb hisoblaymiz. $\varphi(S)$ nisbiy fazaviy o'tkazuvchanlik funksiyalari va fazalarning dinamik qovushqoqliklari nisbati orqali ifodalanuvchi ma'lum funksiyadir: $0 \leq \varphi(S) = \mu_0 \cdot \frac{f_2(S)}{f_1(S) + \mu_0 \cdot f_2(S)} \leq 1$, $\mu_0 = \mu_1 / \mu_2$.

Bu modelda haydovchi quduqda surib chiqaruvchi fazasining to'yinganlik funksiyasiga nisbatan chegaraviy shart

$$S(0, t) = \bar{S} \quad (2)$$

ko'rinishda bo'ladi. Bundan tashqari, surib chiqaruvchi faza to'yinganlik funksiyasining biror

$$S(x, 0) = S_0(x) \quad (3)$$

boshlang'ich taqsimoti berilgan deb hisoblanadi. (1), (2), (3) masalani sonli yechishda (2) chegaraviy shartning amalga oshirilishi qiyinchilik tug'dirmaydi.

Sonli yechish algoritmi. Model tenglamasini sonli yechish uchun chekli ayirmali sxemadan foydalaniladi. Oshkor chekli ayirmali sxema quyidagi ko'rinishga ega:

$$m \cdot \frac{S_i^{j+1} - S_i^j}{\Delta t} + W \cdot \frac{\varphi_i^j - \varphi_{i-1}^j}{\Delta x} = 0 \quad (4)$$

Mazkur sxema yordamida har bir vaqt qatlamida suv to'yinganligi hisoblab boriladi. Natijada suv frontining qatlam bo'ylab surib chiqarishi aniqlanadi.

Qazib olingan neft hajmini aniqlash. Qatlamdagi boshlang'ich neft hajmi quyidagicha aniqlanadi:

$$V_{oil}^0 = mAL \cdot (1 - S_0) \quad (5)$$

bu yerda A - qatlam kesimi yuzasi, L - qatlam uzunligi, S_0 - boshlang'ich suv to'yinganligi. Vaqtning ixtiyoriy momentida qatlamda qolgan neft hajmi quyidagicha aniqlanadi:

$$V_{oil}(t) = mA \int_0^L (1 - S(x, t)) dx \quad (6)$$

Sonli hisoblashlarda integral qiymati yig'indi yordamida hisoblanadi:

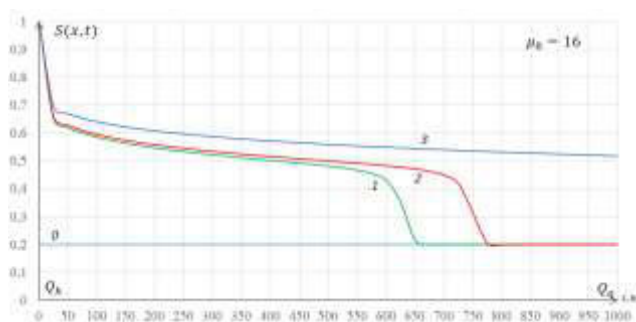
$$V_{oil}(t) \approx mA \sum_{i=1}^N (1 - S_i^n) \Delta x \quad (7)$$

Shunda qazib olingan neft hajmi

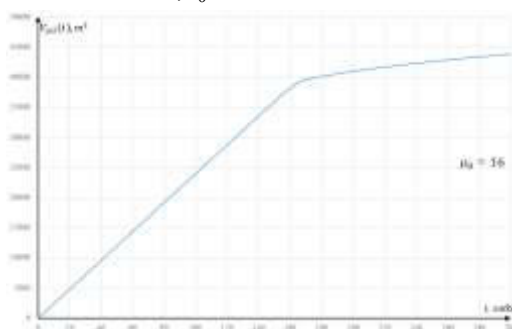
$$Q_{oil}(t) = V_{oil}^0 - V_{oil}(t) \quad (8)$$

formula yordamida aniqlanadi.

Natijalar tahlili. Ushbu maqolada neftni suv bilan surib chiqarish jarayonini sonli modellashtirish bo'yicha hisoblash tajribalari natijalari keltirilgan. $\mu_0 = 16$, $m = 0,3$, $W = 0,6 \frac{m}{sutka}$, $S(x, 0) = 0,2$, $\Delta t = 1$ soat, $\Delta x = 25$ m, $NX = 40$, $L = 1000$ m, $A = 400$ m² bo'lganda Bakley-Leverett modeli bo'yicha olingan natijalarining bir qismi 1-2-rasmlarda keltirilgan.



1-rasm. Surib chiqaruvchi faza to'yinganlik funksiyasining $t=0$ sutka (0-chiziq), $t=100$ sutka (1-chiziq), $t=120$ sutka (2-chiziq), $t=300$ sutka (3-chiziq) vaqt momentlaridagi taqsimotlari,
 $\mu_0 = 16$



2-rasm. $\mu_0 = 16$ bo'lganda qazib oilngan neft hajmi qiymatining vaqt bo'yicha o'sish dinamikasi, t – vaqt momenti.

Hisoblash natijalari shuni ko'rsatadiki, vaqt o'tishi bilan suv fronti qatlam bo'ylab harakatlanadi va neft to'yinganligi kamayib boradi. Suvning harakati natijasida qatlamdan surib chiqarilgan neft hajmi ortadi. Model yordamida suv bilan surib chiqarish samaradorligini, neft berish koeffitsiyentini, qazib olingan neft hajmini aniqlash mumkin.

Xulosa. Maqolada Buckley–Leverett modeli asosida neft konlarida suv bilan surib chiqarish jarayonini matematik modellashtirish masalasi ko'rib chiqildi. Model tenglamasini chekli ayirmali sxema yordamida sonli yechish orqali qatlamdagi suv to'yinganligi va qazib olinadigan neft hajmini aniqlash usuli ishlab chiqildi. Tadqiqot natijalari suv bilan surib chiqarish jarayonining samaradorligini baholash va neft qazib olish jarayonlarini optimallashtirishda qo'llanishi mumkin.

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AUTOMODEL ANALYSIS OF THE FOURTH-ORDER THIN FILM EQUATION

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Abstract. In this work, a fourth-order nonlinear thin film equation is investigated using self-similar transformations. The equation arises in lubrication theory and describes the evolution of a viscous thin liquid film on a solid surface. By introducing similarity variables, the original nonlinear partial differential equation is reduced to an ordinary differential equation. The asymptotic behavior of solutions and numerical properties of similarity profiles are discussed. The obtained results illustrate the effectiveness of the self-similar approach for studying higher-order nonlinear degenerate equations.

Introduction

Thin film equations play an important role in modern mathematical physics, hydrodynamics, and lubrication theory. These equations describe the spreading and deformation of thin viscous

layers under different physical effects. One of the important nonlinear models is the fourth-order thin film equation

$$u_t = -\left(|u|^n u_{xxx}\right)_x$$

Where $u(x, t)$ denotes the film thickness and $n > 0$ is a nonlinear parameter.

The equation is a higher-order degenerate parabolic model and appears in many applied problems connected with capillary forces and viscous flows. In recent years, many authors studied existence, blow-up behavior, similarity solutions, and numerical properties of thin film equations.

The aim of this work is to obtain an automodel (self-similar) form of the equation and investigate the resulting similarity profiles.

Self-Similar Transformation

To construct self-similar solutions, we seek the solution in the form

$$u(x, t) = t^{-\alpha} f(\xi), \quad \xi = xt^{-\beta}$$

where α and β are similarity exponents.

Substituting this transformation into the thin film equation gives

$$-\alpha t^{-\alpha-1} f(\xi) - \beta t^{-\alpha-1} \xi f'(\xi) = -\frac{d}{d\xi} \left(|f|^n f''' \right) t^{-(n+1)\alpha-4\beta}.$$

Balancing the powers of (t), we obtain the relation

$$1 = n\alpha + 4\beta.$$

As a result, the original partial differential equation is reduced to the nonlinear ordinary differential equation

$$\left(|f|^n f''' \right)' + \beta \xi f' + \alpha f = 0.$$

Thus, the automodel transformation reduces the complexity of the original fourth-order equation and allows investigation of qualitative properties of solutions.

Numerical Investigation

The resulting nonlinear ordinary differential equation was investigated numerically. Numerical experiments show that the similarity profiles depend strongly on the nonlinear parameter (n). For small values of (n), the solutions remain smooth and decay monotonically. Increasing (n) leads to stronger nonlinear effects and oscillatory behavior near the interface region.

The numerical analysis demonstrates:

- stability of similarity profiles;
- finite propagation behavior;
- dependence of interface structure on nonlinear parameters;
- asymptotic decay of solutions at infinity.

These properties are important for understanding thin film dynamics and higher-order diffusion processes.

Conclusion

In this work, the fourth-order thin film equation was transformed into a self-similar form using automodel variables. The obtained transformation reduced the nonlinear partial differential equation to an ordinary differential equation. Numerical analysis of the resulting similarity equation showed the existence of stable similarity profiles and revealed important asymptotic properties of solutions.

The self-similar method provides an effective analytical and numerical approach for studying nonlinear higher-order degenerate equations arising in hydrodynamics and thin film theory.

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FRAKTAL TUZILMALI OBYEKTЛАRNI GEOMETRIK MODELLASHTIRISH

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Annotatsiya: Tabiat va texnikada keng tarqalgan fraktal tuzilmali obyektlar o‘zlarining murakkabligi, o‘z-o‘ziga o‘xshashligi va cheksiz detallashtirilganlik xususiyatlari bilan ajralib turadi. An‘anaviy Yevklid geometriyasining cheklangan imkoniyatlari bunday obyektlarni aniq va samarali modellashtirishda sezilarli qiyinchiliklarni keltirib chiqaradi, bu esa geometrik modellashtirishning yangi yondashuvlarini talab qiladi. Ushbu tezisning asosiy maqsadi fraktal tuzilmali obyektlarni raqamli modellashtirishning nazariy asoslarini takomillashtirish, shuningdek, ularni amaliyotda qo‘llashga qaratilgan innovatsion algoritmlar va usullarni ishlab chiqishdan iborat.

Maqolada doirasida takrorlanuvchi funksiya tizimlari (IFS), L-tizimlar va boshqa rekursiv qurish mexanizmlari yordamida fraktal obyektlarning tuzilish xususiyatlari chuqur tahlil qilingan. Fraktal geometriyasi prinsiplariga asoslangan holda, yuqori darajadagi detallashtirish va hisoblash samaradorligini ta‘minlovchi yangi modellashtirish algoritmlari taklif etilgan. Xususan, fraktallarning murakkab topologik xususiyatlarini aks ettiruvchi optimallashtirilgan iterativ usullar ishlab chiqilgan bo‘lib, ular obyektlarning realistik vizualizatsiyasini ta‘minlashga qaratilgan. Tadqiqot natijalari kompyuter grafikasi, tasvirni qayta ishlash, dizayn va ilmiy tadqiqotlarning turli sohalarida fraktal tuzilmali obyektlarni samarali yaratish va tahlil qilish imkonini beradi. Olingan ilmiy natijalar nafaqat nazariy ahamiyatga ega, balki amaliy tatbiqotlarda ham keng qo‘llanilishi mumkin bo‘lgan yangi vositalar va yechimlarni taqdim etadi.

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О ЕДИНСТВЕННОСТИ И РЕГУЛЯРИЗАЦИИ РЕШЕНИЯ ЗАДАЧИ ВОССТАНОВЛЕНИЯ ФУНКЦИИ ПО ИНТЕГРАЛЬНЫМ ДАННЫМ

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Задачи восстановления функций по их интегралам вдоль заданных семейств кривых занимают важное место в теории интегральной геометрии, обратных задачах и математической томографии. Подобные задачи возникают при обработке сигналов, медицинской визуализации, сейсмической разведке, гидродинамике, а также при исследовании процессов, где исходная функция непосредственно не наблюдается, но доступны её интегральные характеристики [1, 2].

Одним из важных классов таких задач являются задачи восстановления функции двух переменных по известным интегралам вдоль семейства окружностей или дуг окружностей. В этом случае неизвестная функция входит под знак интеграла, а исходные данные задаются на некотором семействе кривых. Соответствующие интегральные уравнения, как правило, относятся к классу обратных задач и могут быть некорректно поставленными. Это означает, что малые погрешности во входных данных могут приводить к существенным ошибкам в восстановленном решении [3].

Для преодоления неустойчивости применяются методы регуляризации. В данной работе рассматривается задача восстановления функции $u(x, y)$, заданной в области L_H , по известным интегралам вдоль семейства кривых $\{\Upsilon(x, y_1)\}$. Получается формула обращения в пространстве образов Фурье, а также строится регуляризованное приближённое решение.

Постановка задачи. Рассмотрим в области L_H задачу восстановления функции двух переменных $u(x, y)$ по известным интегралам этой функции вдоль семейства кривых $\{\Upsilon(x, y_1)\}$.

Пусть интегральные данные задаются уравнением (1):

$$\int_{\Upsilon(x, y_1)} g(x, \xi, y_1, \eta) u(\xi, \eta) d\sigma = f(x, y_1) \quad (1)$$

Здесь $d\sigma$ — элемент длины дуги, $g(x, \xi, y_1, \eta)$ — известная весовая функция, а $f(x, y_1)$ — известная функция данных.

Семейство кривых $\Upsilon(x, y_1)$ задаётся следующим образом:

$$\Upsilon(x, y_1) = \{(\xi, \eta) : (x - \xi)^2 + (y_1 - \eta)^2 = y_1^2, 0 \leq \eta \leq y_1 \leq H\}.$$

Таким образом, $\Upsilon(x, y_1)$ представляет собой часть окружности с центром в точке (x, y_1) и радиусом y_1 , расположенную в полосе $0 \leq \eta \leq y_1 \leq H$.

Теорема. Пусть функция $f(x, y_1)$ известна во всех точках (x, y_1) области L_H . Тогда решение интегрального уравнения (1) единственно в классе финитных дважды непрерывно дифференцируемых функций, носитель которых содержится в области L_H .

Пусть функция $\varphi(x, y)$ известна в области L_H . Обозначим через $\hat{\varphi}(\lambda, y)$ преобразование Фурье функции $\varphi(x, y)$ по переменной x :

$$\hat{\varphi}(\lambda, y) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{+\infty} \varphi(x, y) e^{-i\lambda x} dx.$$

Тогда соответствующее интегральное уравнение имеет единственное решение в классе дважды непрерывно дифференцируемых функций. В пространстве образов Фурье это решение записывается в виде:

$$\hat{v}(\lambda, y) = \frac{1}{\pi y} \int_0^y \frac{ch(\lambda \sqrt{y(y-\tau)})}{\sqrt{y-\tau}} \left(\frac{\hat{\varphi}(\lambda, \tau)}{2} + \tau \frac{\partial \hat{\varphi}(\lambda, \tau)}{\partial \tau} \right) d\tau. \quad (2)$$

Для удобства введём обозначение

$$A(\lambda, y) = \int_0^y \frac{ch(\lambda \sqrt{y(y-\tau)})}{\sqrt{y-\tau}} \left(\frac{\hat{\varphi}(\lambda, \tau)}{2} + \tau \frac{\partial \hat{\varphi}(\lambda, \tau)}{\partial \tau} \right) d\tau.$$

Тогда переход от образа Фурье к исходной функции даёт формулу восстановления:

$$u(x, y) = \frac{1}{\pi y \sqrt{2\pi}} \int_{-\infty}^{+\infty} A(\lambda, y) e^{i\lambda x} d\lambda. \quad (3)$$

Формула восстановления (3) содержит множитель

$$ch(\lambda\sqrt{y(y-\tau)}),$$

который быстро возрастает при увеличении $|\lambda|$. Поэтому высокочастотные компоненты данных могут существенно усиливаться. Это приводит к неустойчивости решения относительно малых возмущений функции $\varphi(x, y)$.

Для получения устойчивого приближённого решения вводится регуляризующий оператор

$$R(u, \alpha) = \mathcal{F}^{-1} \left[\hat{u}(\lambda, y) R_2(\lambda, \alpha, y, \tau) \right],$$

где $\alpha > 0$ — параметр регуляризации.

Регуляризующий множитель выберем в виде:

$$R_2(\lambda, \alpha, y, \tau) = \frac{ch^2(\lambda\sqrt{y(y-\tau)})}{ch^2(\lambda\sqrt{y(y-\tau)}) + \alpha(1 + \lambda^2)}.$$

Тогда регуляризованное ядро определяется равенством

$$K_\alpha(\lambda, y, \tau) = ch(\lambda\sqrt{y(y-\tau)}) R_2(\lambda, \alpha, y, \tau).$$

Следовательно,

$$K_\alpha(\lambda, y, \tau) = \frac{ch^3(\lambda\sqrt{y(y-\tau)})}{ch^2(\lambda\sqrt{y(y-\tau)}) + \alpha(1 + \lambda^2)}.$$

Обозначим

$$B_\alpha(\lambda, y) = \int_0^y K_\alpha(\lambda, y, \tau) \frac{1}{\sqrt{y-\tau}} \left(\frac{\hat{\varphi}(\lambda, \tau)}{2} + \tau \frac{\partial \hat{\varphi}(\lambda, \tau)}{\partial \tau} \right) d\tau.$$

Тогда регуляризованное приближённое решение имеет вид:

$$u_\alpha(x, y) = \frac{1}{\pi y \sqrt{2\pi}} \int_{-\infty}^{+\infty} e^{i\lambda x} B_\alpha(\lambda, y) d\lambda.$$

Таким образом, введение множителя $R_2(\lambda, \alpha, y, \tau)$ позволяет ослабить влияние высокочастотных компонент и получить устойчивое приближение к точному решению.

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ В ЗАДАЧАХ ИНТЕГРАЛЬНОЙ ГЕОМЕТРИИ: ФОРМУЛА ОБРАЩЕНИЯ ДЛЯ СПЕЦИАЛЬНОГО СЕМЕЙСТВА КРИВЫХ

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Введение. Задачи интегральной геометрии, связанные с восстановлением функций по их интегралам вдоль заданных семейств кривых, составляют теоретическую основу

компьютерной томографии, дефектоскопии и сейсморазведки. Особый интерес представляют математические модели, в которых кривые интегрирования зависят от параметров нелинейным образом, а весовая функция имеет разрывы. Такие условия возникают при моделировании процессов распространения сигналов в сильно неоднородных или анизотропных средах, где траектории волн претерпевают изломы или экранирование. В данной работе исследуется задача интегральной геометрии с сингулярным семейством кривых и разрывным весом, для которой построена математическая модель и получена точная формула обращения.

Рассматриваемая задача моделирует процесс сканирования двумерной области (x, y) , где $y > 0$ интерпретируется как глубина среды, а x — пространственная координата на поверхности. Семейство кривых $\Gamma(x, y)$ представляет собой симметричные «уголки» с вершиной в точке (x, y) . Параметр $\alpha < 1$ управляет нелинейностью геометрии среды: при $\alpha \rightarrow 1$ кривые стремятся к характеристическим линиям стандартного волнового уравнения, а при $\alpha < 1$ моделируют среду с переменной скоростью распространения возмущений, зависящей от глубины.

Кусочно-постоянная весовая функция $g(x, \xi)$ моделирует эффект одностороннего экранирования или направленного излучения (например, когда детекторы регистрируют сигналы, приходящие только с одной стороны от источника, $\xi > x$). Функция $f(x, y)$ представляет собой измеряемый на выходе суммарный сигнал (интенсивность), полученный в результате интегрального преобразования неизвестного распределения плотности неоднородностей $u(\xi, \eta)$.

Постановка задачи

В рамках предложенной модели математически задача восстановления плотности сводится к определению функции $u(\xi, \eta)$ по семейству интегралов:

$$\int_{\Gamma(x, y)} g(x, y; \xi, \eta) u(\xi, \eta) ds = f(x, y),$$

где интегрирование ведется по кривым:

$$\Gamma(x, y) = \{(\xi, \eta) : |x - \xi| = y^\alpha - \eta^\alpha\}, \quad \alpha < 1.$$

Весовая функция имеет вид:

$$g(x, \xi) = \begin{cases} 1, & x < \xi \\ 0, & x > \xi \end{cases}$$

Функция $f(x, y)$ считается известной (заданной на основе экспериментальных измерений).

Теорема. Пусть функция $f(x, y)$ достаточно гладкая и убывает на бесконечности по переменной x вместе со своими производными. Тогда решение задачи интегральной геометрии (восстановление функции $u(x, y)$) определяется явной формулой обращения:

$$u(x, y) = \frac{1}{\sqrt{y^{2(1-\alpha)} + \alpha^2}} \left(y^{1-\alpha} f'_y(x, y) + f'_x(x, y) \right)$$

К исходному интегральному уравнению применяется интегральное преобразование Фурье по пространственной переменной x , что позволяет перевести операцию свертки по координате в алгебраическое умножение в частотной области. Полученное соотношение дифференцируется по переменной глубины y , благодаря чему удается избавиться от интегральной зависимости в операторе. Применяется обратное преобразование Фурье, возвращающее решение из частотной области в координатное пространство, что приводит к искомому дифференциальному оператору над измеряемой функцией $f(x, y)$.

EXPLICIT GREEN'S FUNCTION RECONSTRUCTION FOR A WEIGHTED BROKEN-RAY TRANSFORM

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Abstract. This paper considers an inverse problem of integral geometry associated with a weighted broken-ray transform in a strip domain. The unknown function is integrated along a family of V-shaped trajectories that naturally arise in seismic wave propagation [1]. An explicit inversion formula is derived by reducing the problem to a Poisson equation and applying Green's function of the two-dimensional Laplace operator. The resulting reconstruction is represented as a convolution with an explicitly calculated singular kernel. A regularized version of the inversion formula is also discussed, providing a stable analytical and numerical framework for wave field reconstruction from integral measurements.

Statement of the Problem: Let $L_H = \mathbb{R} \times (0, H)$, $H > 0$, and let $u(\xi, \eta) \in C_0^2(L_H)$ be an unknown function. For each point $(x, y) \in L_H$, define the broken-line trajectory $S(x, y) = \{(\xi, \eta) \in L_H : |x - \xi| = y - \eta, 0 < \eta \leq y\}$ which consists of two straight-line segments.

Assume that the following weighted integral of the function u is known:

$$\int_{S(x,y)} (y - \eta) u(\xi, \eta) ds = f(x, y), \quad (x, y) \in L_H,$$

where $f(x, y)$ is a prescribed function and ds denotes the differential arc length along the curve $S(x, y)$. The inverse problem consists in reconstructing the function $u(\xi, \eta)$ from the measured data $f(x, y)$.

It is established that the function $u(x, y)$ satisfies the differential identity

$$\Delta u(x, y) = \frac{\sqrt{2}}{4} \left(\frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2} \right)^2 f(x, y), \quad (x, y) \in L_H, \quad (1)$$

where $\Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$ is the Laplace operator.

Equation (1) reduces the inverse problem to the Poisson equation

$$\Delta u(x, y) = g(x, y),$$

where $g(x, y) = \frac{\sqrt{2}}{4} (\partial_x^2 - \partial_y^2)^2 f(x, y)$.

Using the Green's function of the two-dimensional Laplace operator

$$G(X, Y) = \frac{1}{4\pi} \ln(X^2 + Y^2),$$

the solution can be represented as

$$u(x, y) = \iint_{\mathbb{R}^2} G(x - \xi, y - \eta) g(\xi, \eta) d\xi d\eta.$$

After integrating by parts, the derivatives are transferred from f to the Green's function, yielding the explicit inversion formula

$$u(x, y) = \frac{\sqrt{2}}{4} \iint_{\mathbb{R}^2} K(x - \xi, y - \eta) f(\xi, \eta) d\xi d\eta, \quad (2)$$

where $K(X, Y) = \left(\frac{\partial^2}{\partial X^2} - \frac{\partial^2}{\partial Y^2} \right)^2 G(X, Y)$.

A direct calculation gives $K(X, Y) = \frac{12}{\pi} \frac{X^2 Y^2}{(X^2 + Y^2)^4} - \frac{2}{\pi} \frac{1}{(X^2 + Y^2)^2}$.

Formula (2) provides an explicit analytical reconstruction of the unknown function from the measured data. This representation forms the basis for efficient numerical algorithms and regularization procedures. The obtained results can be applied to seismic imaging and other inverse problems involving generalized Radon transforms.[2]

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HOSILDORLIK NOANIQLIGI SHAROITIDA QISHLOQ XO‘JALIGI MAHSULOTLARINI ISHLAB CHIQARISHNI IKKI BOSQICHLI STOXTASTIK MODELLASHTIRISH

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Qishloq xo‘jaligi ishlab chiqarishida rejalashtirish qarorlari yer, suv, mehnat, yem-xashak va moliyaviy resurslar bilan cheklanadi. Bunday tizimda faqat bitta iqtisodiy ko‘rsatkichni optimallashtirish yetarli emas: daromadni ko‘paytirishga qaratilgan reja suv sarfini oshirishi, xarajatni keskin kamaytirish esa mahsulot hajmi va iqtisodiy natijani pasaytirishi mumkin. Shu sababli agrar ishlab chiqarishni matematik modellashtrishda xarajat, daromad va resurs samaradorligi mezonlari birgalikda qaraladi [1,2]. Amaliy jihatdan masalaning murakkab tomoni shundaki, ekin hosildorligi tabiiy-iqlimiy sharoit, suv ta‘minoti va agrotexnik tadbirlarning bajarilish darajasiga bog‘liq bo‘lib, u oldindan qat‘iy qiymat sifatida qabul qilinsa, qarorlar real vaziyatga yetarli darajada moslashmasligi mumkin. Shu nuqtai nazardan, hosildorlikni tasodifiy parametr sifatida qarovchi ikki bosqichli stoxastik yondashuv respublikamiz hududlari uchun dolzarb ilmiy-amaliy masala hisoblanadi.

Aytilik, I – fermer xo‘jaliklari to‘plami, J – ekinlar to‘plami, K – chorva turlari to‘plami, M – ozuqa komponentlari to‘plami, Θ esa hosildorlik noaniqligini ifodalovchi tabiat holatlari yoki ssenariylar to‘plami bo‘lsin. Har bir $\theta \in \Theta$ holatda $a_{ij}(\theta)$ – i -xo‘jalikdagi j -ekin hosildorligining realizatsiyasini bildiradi. Hosildorlik hali noma‘lum bo‘lgan sharoitda birinchi bosqich qarorlari tanlanadi: x_{ij} – i -xo‘jalikda j -ekin uchun ajratiladigan yer maydoni, z_{ik} – i -xo‘jalikda k -tur chorvachilik faoliyati hajmi. Tasodifiy parametr θ ma‘lum bo‘lgandan keyin ikkinchi bosqich tuzatuvchi qarorlar aniqlanadi: $y_{ij}(\theta)$ – hosilning yem-xashakka yo‘naltiriladigan qismi, $u_j(\theta)$ – qondirilmay qolgan talab miqdori, $w_{im}(\theta)$ – bozordan xarid qilinadigan qo‘shimcha yem miqdori.

Uch mezonli modelda birinchi mezon jami ishlab chiqarish xarajatlarini minimallashtirishga, ikkinchi mezon kutilayotgan sof daromadni maksimallashtirishga, uchinchi mezon esa suv sarfini minimallashtirishga yo‘naltiriladi:

$$f_1(x, z) = \sum_{i \in I} \sum_{j \in J} q_{ij} x_{ij} + \sum_{i \in I} \sum_{k \in K} \hat{q}_{ik} z_{ik} \rightarrow \min, \quad (1)$$

$$f_2(x, z) = \mathbb{E}_{\theta} \left[\sum_{i \in I} \sum_{j \in J} P_{ij} a_{ij}(\theta) x_{ij} - Q(x, z, \theta) \right] + \sum_{i \in I} \sum_{k \in K} \hat{P}_{ik} z_{ik} \rightarrow \max, \quad (2)$$

$$f_3(x, z) = \sum_{i \in I} \sum_{j \in J} \omega_{ij} x_{ij} + \sum_{i \in I} \sum_{k \in K} \hat{\omega}_{ik} z_{ik} \rightarrow \min. \quad (3)$$

Bu yerda $Q(x, z, \theta)$ funksiyasi berilgan (x, z) birinchi bosqich qarorlari va θ holati uchun minimal ikkinchi bosqich tuzatuvchi xarajatni bildiradi. Uning mazmuni talab yetishmovchiligi uchun jarima, qo'shimcha yem xaridi hamda hosilni yem-xashakka ajratish bilan bog'liq yo'qotishlarni minimallashtirishdan iborat bo'ladi:

$$Q(x, z, \theta) = \min_{y(\theta), u(\theta), w(\theta)} \sum_{j \in J} C_j u_j(\theta) + \sum_{i \in I} \sum_{m \in M} H_m w_{im}(\theta) + \sum_{i \in I} \sum_{j \in J} P_{ij} y_{ij}(\theta). \quad (4)$$

Ikkinchi bosqich masalasi talabni qondirish, yem balansi va mavjud hosil hajmidan oshmaslik cheklovlari bilan beriladi:

$$\sum_{i \in I} (a_{ij}(\theta) x_{ij} - y_{ij}(\theta)) + u_j(\theta) \geq A_j, \quad j \in J, \theta \in \Theta, \quad (5)$$

$$\sum_{j \in J} b_{jm} y_{ij}(\theta) + w_{im}(\theta) \geq \sum_{k \in K} \hat{b}_{ikm} z_{ik}, \quad i \in I, m \in M, \theta \in \Theta, \quad (6)$$

$$0 \leq y_{ij}(\theta) \leq a_{ij}(\theta) x_{ij}, \quad u_j(\theta) \geq 0, \quad w_{im}(\theta) \geq 0, \quad i \in I, j \in J, m \in M, \theta \in \Theta. \quad (7)$$

Birinchi bosqich qarorlari esa yer, mehnat, chorvachilik sig'imi va texnologik imkoniyatlar bilan cheklanadi:

$$\sum_{j \in J} x_{ij} \leq S_i, \quad i \in I, \quad (8)$$

$$\sum_{j \in J} t_{ij} x_{ij} + \sum_{k \in K} \hat{t}_{ik} z_{ik} \leq T_i, \quad i \in I, \quad (9)$$

$$\sum_{i \in I} z_{ik} \geq B_k, \quad k \in K, \quad (10)$$

$$0 \leq x_{ij} \leq \delta_{ij} X_{ij}^{\max}, \quad i \in I, j \in J, \quad (11)$$

$$0 \leq z_{ik} \leq \gamma_{ik} Z_{ik}^{\max}, \quad i \in I, k \in K. \quad (12)$$

(8)-(12) cheklovlar xo'jalikning yer maydoni, mehnat resursi, chorvachilik bo'yicha minimal talab, ekin ekish imkoniyati va chorva sig'imini ifodalaydi. Shunday qilib, stoxastik model strategik qarorlarni hosildorlik noma'lum davrda tanlaydi, keyingi bosqichda esa real hosildorlikka mos ravishda tuzatuvchi qarorlar orqali rejaning bajarilishini saqlab qoladi.

Shunday qilib, taklif etilayotgan model hosildorlik noaniqligi sharoitida ekin maydonlari taqsimoti, chorvachilik hajmi, yem-xashak balansi va suv sarfini birgalikda rejalashtirish imkonini beradi. Amaliy rejalashtirishda modeldan fermer xo'jaliklari kesimida resurs cheklovlarini buzmaganda xarajat, daromad va suv sarfi mezonlari bo'yicha Pareto-samarali boshqaruv variantlarini tanlash uchun foydalanish tavsiya etiladi.

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ISSIQLIK O'TKAZUVCHANLIK TENGLAMALARIGA TO'G'RI VA TESKARI MASALALARNING PYTHON DASTURLASH TILIDA YECHIMLARI

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Annotatsiya: Ushbu maqolada issiqlik o'tkazuvchanlik tenglamalariga to'g'ri (direct) va teskari (inverse) masalalar ko'rib chiqiladi. To'g'ri masalada — berilgan issiqlik manbai va chegara shartlari asosida temperatura maydonini topish; teskari masalada — o'lchash natijalaridan kelib chiqib, noma'lum parametrlar (issiqlik o'tkazuvchanlik koeffitsienti, manba intensivligi va h.k.) ni tiklash ko'zda tutiladi. Har bir masala uchun Python dasturlash tilida amaliy kodlar keltirilgan.

Issiqlik o'tkazuvchanlik tenglamasi ko'plab muhandislik va fizik masalalarning matematik modelidir. U issiqlik energiyasining bir muhitdan ikkinchisiga o'tishini tavsiflaydi. Bu tenglama bir o'lchovli holda quyidagi ko'rinishga ega:

$$\partial T / \partial t = \alpha \cdot \partial^2 T / \partial x^2$$

Bu yerda T — temperatura ($^{\circ}\text{C}$ yoki K), t — vaqt (s), x — fazoviy koordinata (m), $\alpha = \lambda / (\rho \cdot c)$ — issiqlik diffuzivligi (m^2/s), λ — issiqlik o'tkazuvchanlik koeffitsienti ($\text{W}/\text{m} \cdot \text{K}$), ρ — zichlik (kg/m^3), c — solishtirma issiqlik sig'imi ($\text{J}/\text{kg} \cdot \text{K}$).

To'g'ri masala: α , boshlang'ich va chegara shartlari berilgan holda $T(x, t)$ ni topish. Teskari masala: ba'zi o'lchash ma'lumotlaridan α yoki boshqa parametrlarni aniqlash.

Matematik qo'yilishi: Bir o'lchovli issiqlik o'tkazuvchanlik masalasini ko'ramiz:

$$\partial T / \partial t = \alpha \cdot \partial^2 T / \partial x^2, \quad 0 < x < L, \quad 0 < t \leq t_{\max}$$

Boshlang'ich shart: $T(x, 0) = T_0(x)$
 Chegara shartlari: $T(0, t) = T_{\text{left}}, \quad T(L, t) = T_{\text{right}}$

Ushbu masalani hal qilish uchun sonli usullardan biri bo'lgan chekli ayirmalar usuli (finite difference method) qo'llaniladi. Vaqt bo'yicha noaniq sxema (implicit scheme) yoki aniq sxema (explicit scheme) ishlatilishi mumkin.

Aniq sxema (Explicit Scheme)

Aniq sxemada yangi vaqt qadamidagi qiymat faqat oldingi qadamdagi qiymatlar orqali hisoblanadi. Barqarorlik sharti: $r = \alpha \cdot \Delta t / \Delta x^2 \leq 0.5$ bo'lishi lozim.

import numpy as np
import matplotlib.pyplot as plt
Parametrlar
L = 1.0 # Rod uzunligi (m)
T_max = 0.5 # Maksimal vaqt (s)
alpha = 0.01 # Issiqlik diffuzivligi (m^2/s)
N = 50 # Fazoviy tugunlar soni
dx = L / N
dt = 0.4 * dx**2 / alpha # Barqarorlik sharti: r <= 0.5
M = int(T_max / dt)
r = alpha * dt / dx**2
Boshlang'ich shart: T(x,0) = sin(pi*x/L)
x = np.linspace(0, L, N+1)

T = np.sin(np.pi * x / L)
Chegara shartlari
T[0] = 0.0
T[-1] = 0.0
Vaqt integratsiyasi
T_history = [T.copy()]
for n in range(M):
T_new = T.copy()
T_new[1:-1] = T[1:-1] + r*(T[2:] - 2*T[1:-1] + T[:-2])
T_new[0] = 0.0
T_new[-1] = 0.0
T = T_new.copy()
if n % (M//5) == 0:
T_history.append(T.copy())
Vizualizatsiya
plt.figure(figsize=(10, 6))
for i, T_plot in enumerate(T_history):
plt.plot(x, T_plot, label=f't={i*T_max/5:.2f}s')
plt.xlabel('x (m)')
plt.ylabel('T (°C)')
plt.title("Issiqlik tarqalishi (Aniq sxema)")
plt.legend()
plt.grid(True)
plt.tight_layout()
plt.show()

Aniq sxema sodda bo'lsa-da, barqarorlik shartiga qat'iy rioya qilishni talab etadi. Katta Δt qiymati natijani noto'g'ri beradi.

Noaniq sxema (Implicit Scheme — Crank-Nicolson)

Crank-Nicolson sxemasi 2-tartibli aniqlikka ega va har doim barqaror. U chiziqli tenglama sistemasini yechishni talab etadi, lekin katta vaqt qadamlarida ham ishonchli natija beradi.

import numpy as np
from scipy.linalg import solve_banded
def crank_nicolson(L, T_max, alpha, N, M):
dx = L / N
dt = T_max / M
r = alpha * dt / (2 * dx**2)
x = np.linspace(0, L, N+1)
T = np.sin(np.pi * x / L).copy()

<code>T[0] = 0.0; T[-1] = 0.0</code>
<code># Uchlik diagonal matritsa (tridiagonal)</code>
<code>main = np.ones(N-1) * (1 + 2*r)</code>
<code>lower = np.ones(N-2) * (-r)</code>
<code>upper = np.ones(N-2) * (-r)</code>
<code>results = {'x': x, 'T_list': [T.copy()], 'times': [0.0]}</code>
<code>for n in range(M):</code>
<code> # O'ng tomon</code>
<code> rhs = T[1:-1].copy()</code>
<code> rhs[1:-1] += r*(T[1:-2] - 2*T[2:-2] + T[3:-1])</code>
<code> rhs[0] += r * T[0]</code>
<code> rhs[-1] += r * T[-1]</code>
<code># Thomas algoritmi (scipy)</code>
<code>ab = np.zeros((3, N-1))</code>
<code>ab[0, 1:] = upper</code>
<code>ab[1, :] = main</code>
<code>ab[2, :-1] = lower</code>
<code>T_inner = np.linalg.solve(</code>
<code> np.diag(main) + np.diag(lower, -1) + np.diag(upper, 1), rhs</code>
<code>)</code>
<code>T[1:-1] = T_inner</code>
<code>results['T_list'].append(T.copy())</code>
<code>results['times'].append((n+1)*dt)</code>
<code>return results</code>
<code>res = crank_nicolson(L=1.0, T_max=0.5, alpha=0.01, N=50, M=100)</code>
<code>print('Crank-Nicolson yechimi muvaffaqiyatli!')</code>

XULOSA

Ushbu maqolada issiqlik o'tkazuvchanlik tenglamalariga to'g'ri va teskari masalalar Python dasturlash tilida yechildi. To'g'ri masala uchun ikki usul — aniq sxema va Crank-Nicolson sxemasi — ko'rib chiqildi. Aniq sxema oddiy va tez, lekin barqarorlik shartiga bog'liq. Crank-Nicolson esa barcha vaqt qadamlarida barqaror va ikkinchi tartib aniqlikka ega.

Teskari masala uchun `scipy.optimize.minimize` asosida gradient optimallashtirish ishlatildi. Shovqinli ma'lumotlar uchun Tikhonov regularizatsiyasi qo'llanildi, bu esa yechimning barqarorligini oshiradi. Amaliy natijalar shuni ko'rsatdiki, sensor o'lchashlari sifati teskari masala yechimining aniqligiga bevosita ta'sir qiladi.

Kelgusida ushbu usullarni ko'p o'lchovli (2D/3D) va nochiziqli issiqlik o'tkazuvchanlik masalalariga, shuningdek real muhandislik tizimlari uchun kengaytirish mumkin.

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МОДЕЛИРОВАНИЕ ПЛАСТИЧЕСКИХ ДЕФОРМАЦИЙ В НЕЛОКАЛЬНОЙ МОДЕЛИ ПОРОУПРУГОСТИ

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Аннотация: Рассматривается нелокальная модель деструкции насыщенной жидкостью пористой среды. Показано влияние пластических деформаций на параметры периодической зоной структуры.

Наблюдаемые процессы периодической деформации внутренней структуры горных пород и зональной дезинтеграции пород вокруг подземных выработок [1,2] описывались на основе различных моделей пластичности [3]. В работе [4] в качестве параметра состояния среды было предложено выбрать тензор кривизны. В результате теория становится нелокальной и, как следствие, возникает пространственная периодическая структура, которая может трактоваться как развитие зональной дезинтеграции среды. В работе [5] рассмотрены нестационарная модель дезинтеграции в однородной среде и показано, что нестационарные режимы приводят к увеличению напряжений в зонах дезинтеграции. В настоящей работе рассматривается роль диссипативных процессов в модели [6], обобщающей нелокальную теорию упругости [4,5] на насыщенные пористые среды.

Математическая модель неупругой деформации насыщенной пористой среды основана на фундаментальных физических принципах: законах сохранения, началах термодинамики, групповой инвариантности дифференциальных уравнений. Локальными параметрами состояния пористой среды являются: парциальные плотности и скорости пористой матрицы $\{\rho_s, \mathbf{u}\}$ и насыщающей жидкости $\{\rho_l, \mathbf{v}\}$, тензор деформации ε_{ik} и кривизна $R = 2(\partial_i \partial_k \varepsilon_{ik} - \Delta \varepsilon_{ll})$, которая отождествляется с параметром деструкции. Локальная термодинамика двухскоростной среды определяется заданием функциональной зависимости внутренней энергии $e_0(\rho, \varepsilon_{ik}, R, |\mathbf{u} - \mathbf{v}|)$. Давление p , тензор напряжений σ_{ik} и параметр деструкции $\bar{\gamma}$ в линейном приближении принимают вид

$$p = (\gamma + K) \frac{\delta \rho}{\rho_0} + K \varepsilon_{ll} + c_3 R, \quad (1)$$

$$\sigma_{ik} = -\gamma \frac{\delta \rho}{\rho_0} \delta_{ik} + 2\mu \left(\varepsilon_{ik} - \frac{1}{3} \varepsilon_{ll} \delta_{ik} \right) + (c_2 - c_3) R \delta_{ik}, \quad (2)$$

$$\bar{\gamma} = c_3 \frac{\delta \rho}{\rho_0} + c_2 \varepsilon_{ll} + c_1 R, \quad (3)$$

где λ , μ , γ – упругие модули насыщенной пористой среды, $K = \lambda + 2\mu$; c_1 , c_2 , c_3 – энергетические модули. Переменные с нулевыми индексами относятся к начальному равновесному состоянию.

Уравнения движения двухскоростной среды с учетом параметра деструкции в приближении малых деформаций имеют вид

$$\frac{\partial \rho}{\partial t} + \rho_s \partial_x u_x + \rho_l \partial_x v_x = 0, \quad (4)$$

$$\frac{\partial \varepsilon_{xx}}{\partial t} - \partial_x u_x = -\bar{\phi}_{xx}, \quad \frac{\partial \varepsilon_{yy}}{\partial t} = -\bar{\phi}_{yy}, \quad (5)$$

$$\frac{\partial u_x}{\partial t} - \frac{1}{\rho_s} \partial_x \sigma_{xx} - \frac{\rho_l}{\rho_s \rho_0} \partial_x p = -\frac{\rho_l}{\rho_s} b(u_x - v_x), \quad (6)$$

$$\frac{\partial v_x}{\partial t} + \frac{1}{\rho_0} \partial_x p = b(u_x - v_x), \quad (7)$$

$$\frac{\partial R}{\partial t} + \partial_x u_x = -2 \partial_x^2 \bar{\phi}_{xx}, \quad (8)$$

где $\bar{\phi}_{xx} = \xi (\bar{\sigma}_{xx} + \partial_{xx}^2 \bar{\gamma})$ – источник пластических деформаций.

Здесь $\rho = \rho_s + \rho_l$ – плотность двухскоростной среды, $\rho_s = \rho_* \sqrt{\det(1 - 2\varepsilon_{ik})}$ – парциальная плотность пористой матрицы, $\rho_* = \text{const}$; ξ – пластический коэффициент; $b = \eta/\rho k$ – коэффициент межфазного трения Дарси, η – динамическая вязкость насыщающей жидкости, k – пористость.

Для исследования деформированного состояния среды в процессе нагружения рассматривается нестационарная одномерная задача о сжатии однородного слоя конечной толщины $x \in [X_1, X_2]$. Параметры насыщенной пористой среды соответствуют параметрам горной породы. На границах слоя предполагается

$$\bar{\gamma} = 0, \quad \partial \bar{\gamma} / \partial x = 0. \quad (9)$$

Напряжение на левой и правой границах задано как функция времени

$$\sigma_{xx} = -P_1(t), \quad \frac{\rho_l^{ph}}{\rho_0} p = P_2(t). \quad (10)$$

Здесь ρ_l^{ph} – физическая плотность насыщающей жидкости, ϕ – пористость: $\rho_l = \phi \rho_l^{ph}$; $P_1(t)$, $P_2(t)$ – функции времени вида $P_i(t) = \sum_i (1 - e^{-t/\tau_i})$, $\sum_i$, τ_i – параметры.

Задача (4)–(10) решалась численно методом Рунге-Кутты третьего порядка точности по времени с WENO реконструкцией переменных, входящих в потоки гиперболической части уравнений [3]. Численное моделирование деформации упруго-пластичного слоя показывает сильное влияние пористости среды на интенсивность деструкции и характерный масштаб периодической структуры, образующейся под действием внешних напряжений, прикладываемых к упругой матрице и к заполняющей ее жидкости. При большом соотношении P_2/P_1 напряжения в зонах деструкции увеличиваются на десятки процентов [6]. Диссипативные процессы пластических деформаций, определяемых параметром ξ , приводят к ослаблению деструкции. На рис. 1 показано изменение максимальных значений амплитуд кривизны R и напряжений σ_{yy} для первой области деструкции при увеличении значения коэффициента пластичности ξ . При заметном увеличении локальной кривизны компоненты напряжений σ_{yy} уменьшаются на $\sim 5\%$.

Графики кривизны и напряжения представлены в момент времени 294 мкс.

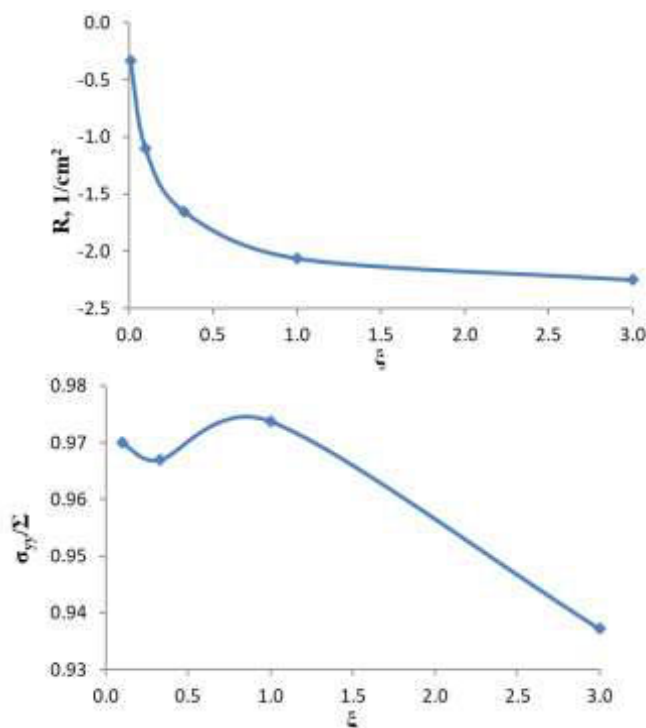


Рис. 1. Максимальные значения амплитуд кривизны R и напряжений σ_{yy} для первой области деструкции в зависимости от значения коэффициента пластичности ξ .

Исследования выполнены в рамках государственного задания ИВМиМГ СО РАН FWNM-2025-0004.

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POPULYATSIYA JARAYONLARINI MODELLASHTIRISHDA (LOTKA–VOLTERRA MODELI MISOLIDA)

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Annotatsiya. Ushbu ish populyatsiya jarayonlarini matematik modellashtirish masalalariga bag‘ishlangan bo‘lib, unda Lotka–Volterra modeli asosida yirtqich va o‘lja populyatsiyalari o‘rtasidagi o‘zaro munosabatlar tahlil qilinadi. Populyatsiya dinamikasi zamonaviy tabiiy fanlarda

fundamental ilmiy muammolardan biri hisoblanadi. Tadqiqotda matematik modellashtirish usullarining biologik tizimlarni o'rganishdagi ahamiyati yoritilib, Lotka–Volterra differensial tenglamalari orqali populyatsiyalar sonining vaqt bo'yicha o'zgarishi grafik va diagrammalar yordamida tushuntiriladi. Olingan natijalar ekologik muvozanatni anglash, tabiiy resurslardan oqilona foydalanish hamda zamonaviy tabiiy fanlar rivojida matematik modellar muhim o'rin tutishini ko'rsatadi.

Kalit so'zlar: populyatsiya, matematik modellashtirish, Lotka–Volterra modeli, yirtqich–o'lja tizimi, populyatsiya dinamikasi, tabiiy fanlar.

KIRISH: Zamonaviy tabiiy fanlarning eng muhim vazifalaridan biri tabiatda sodir bo'ladigan murakkab jarayonlarni chuqur tahlil qilish va ularni ilmiy asosda tushuntirishdan iboratdir. Ayniqsa, biologik tizimlarda populyatsiyalarning o'sishi, kamayishi va o'zaro ta'siri fundamental ilmiy muammolardan biri hisoblanadi. Bu jarayonlar ekologik muvozanat, biologik xilma-xillik va barqaror rivojlanish bilan bevosita bog'liqdir. Populyatsiya jarayonlarini o'rganishda matematik modellashtirish muhim o'rin tutadi. Matematik modellar orqali real jarayonlar soddalashtiriladi, ularning asosiy qonuniyatlari aniqlanadi va kelajakdagi holatlari bashorat qilinadi. Shunday modellar ichida Lotka–Volterra modeli alohida ahamiyatga ega bo'lib, u yirtqich va o'lja populyatsiyalari o'rtasidagi munosabatlarni ifodalaydi. Ushbu ishda Lotka–Volterra modeli fundamental ilmiy muammo sifatida ko'rib chiqilib, uning zamonaviy tabiiy fanlar rivojidagi o'rni va ahamiyati yoritiladi[1].

1. POPULYATSIYA TUSHUNCHASI VA UNI O'RGANISHNING ILMIY AHAMIYATI. Populyatsiya – bu muayyan hududda yashovchi, bir turga mansub va o'zaro erkin ko'payish qobiliyatiga ega bo'lgan organizmlar majmuasidir. Populyatsiyalar soni vaqt davomida tug'ilish, o'lim, migratsiya va tashqi muhit omillari ta'sirida o'zgaradi.

1.1. Yirtqich–o'lja o'zaro ta'siri (3D sxema). Grafik: 3D blok diagramma yoki sfera shaklida, o'lja (x) va yirtqich (y) soni o'qlar bo'yicha, z o'qi – vaqt. Tahlil: O'lja populyatsiyasi yirtqichlar sonining oshishiga sabab bo'ladi. Yirtqichlar o'lja hisobiga ko'payadi, ammo o'lja kamayishi bilan yirtqichlar ham kamayadi. Bu yopiq sikl tizimni dinamik muvozanatda ushlab turadi.

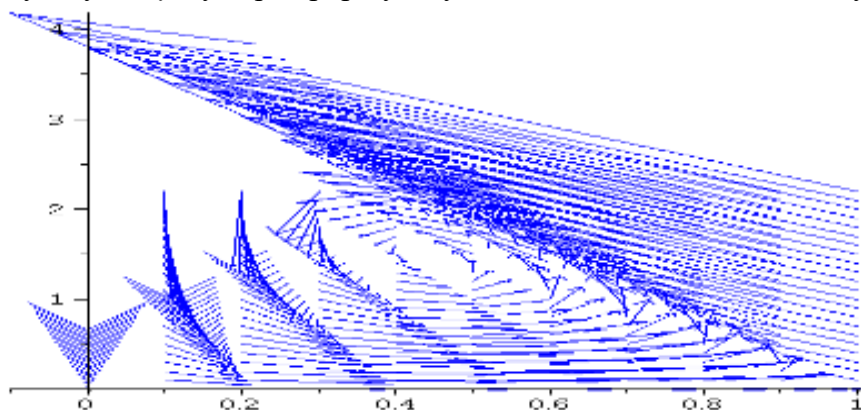
2. MATEMATIK MODELASHTIRISH

Matematik modellashtirish murakkab biologik jarayonlarni tenglamalar yordamida ifodalash imkonini beradi. Bu usul orqali real jarayon soddalashtiriladi va asosiy qonuniyatlar aniqlanadi.

Lotka–Volterra tenglamalari:

$$\begin{cases} \frac{dx}{dt} = ax - bxy \\ \frac{dy}{dt} = -cy + dxy \end{cases} \quad (1)$$

x – o'lja populyatsiyasi; y – yirtqich populyatsiyasi; a, b, c, d – musbat koeffitsiyentlar



1-rasm. Lotka-Volterra modeli uchun fazoviy diagramma

Grafikda x – o‘q o‘lja populyatsiyasini, y – o‘q esa yirtqich populyatsiyasini ifodalaydi. Har bir nuqtada ko‘rsatilgan kichik o‘qchalar (vektorlar) tizimning shu nuqtadagi o‘zgarish yo‘nalishi va tezligini bildiradi. O‘qchalar qayerga qarab ketayotganiga qarab, o‘lja va yirtqich populyatsiyalarining qanday dinamikasi yuz berishi kuzatiladi. Markaz atrofida yopiq siklik harakatlar (aylanalar) mavjud — bu ikki populyatsiyaning davriy o‘zaro ta‘sirini, ya‘ni o‘lja ko‘payadi, keyin yirtqichlar ko‘payadi, so‘ng o‘lja kamayadi va keyin yirtqich kamayadi, shunday aylana takrorlanishini anglatadi. Tashqi hududlarda o‘qchalar uzun va qattiq ko‘rsatkichlar bilan o‘zgarish tezligini bildiradi, ya‘ni tizimning u yerda o‘zgarishi tezroq sodir bo‘ladi. Bu fazoviy diagramma Lotka-Volterra tenglamalari asosida biologik populyatsiyalarning vaqt bo‘yicha qanday harakat qilishini vizual tarzda ko‘rsatadi.

Masala. Bir hududda o‘lja (quyonlar) va yirtqich (bo‘rilar) populyatsiyalari mavjud. Ularning o‘zaro ta‘siri Lotka-Volterra modeliga muvofiq ifodalanadi:

$$\begin{cases} \frac{dx}{dt} = 0.6x - 0.02xy \\ \frac{dy}{dt} = -0.4y + 0.01xy \end{cases} \quad (2)$$

Bu yerda: $x(t)$ – o‘lja populyatsiyasi soni (quyonlar); $y(t)$ – yirtqich populyatsiyasi soni (bo‘rilar); 0.6 – o‘lja populyatsiyasining tabiiy o‘sish darajasi; 0.02 – yirtqichlar tomonidan o‘ljaning kamayish koeffitsiyenti; 0.4 – yirtqichlarning tabiiy o‘lim darajasi; 0.01 – yirtqichlarning o‘lja hisobidan ko‘payish koeffitsiyenti.

Savol:

1. Tizimning barqaror nuqtasini toping.
2. Barqaror nuqtada populyatsiyalar sonini aniqlang.
3. Ushbu nuqta biologik ma‘noda mantiqiy ekanligini tushuntiring.

YECHIM: 1) Barqaror nuqtani toppish. Barqaror nuqtada populyatsiyalar o‘zgarishi to‘xtaydi, ya‘ni: $\frac{dx}{dt} = 0, \frac{dy}{dt} = 0$ Tenglamalarni yechamiz: $0.6x - 0.02xy = 0 \Rightarrow x(0.6 - 0.02y) = 0$

Bu yerda ikki holat bo‘lishi mumkin:

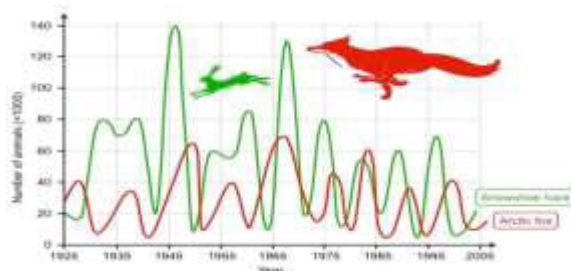
1. $x = 0$ (o‘lja yo‘q bo‘lsa)
2. $0.6 - 0.02y = 0 \Rightarrow y = \frac{0.6}{0.02} = 30$

Ikkinchi tenglama uchun: $-0.4y + 0.01xy = 0 \Rightarrow y(-0.4 + 0.01x) = 0$

Yana ikki holat:

1. $y = 0$ (yirtqich yo‘q bo‘lsa)
2. $-0.4 + 0.01x = 0 \Rightarrow x = \frac{0.4}{0.01} = 40$

2) Barqaror nuqtalar: $(x, y) = (0, 0)$ – ikkala populyatsiya yo‘q; $(x, y) = (40, 30)$ – barqaror nuqta (populyatsiyalar doimiy holatda) b) Barqaror nuqtada populyatsiyalar soni: $x^* = 40, y^* = 30$. Demak, bu modelga ko‘ra, vaqt o‘tishi bilan quyonlar soni 40 ga, bo‘rilar soni esa 30 ga barqarorlashadi.



2-rasm. O‘lja va yirtqich munosabatlari grafigi

3) Biologik ma'nosi. Bu nuqta populyatsiyalar o'zgarishi to'xtaydigan, muvozanat holatini ifodalaydi; x^* va y^* musbat sonlar bo'lib, bu o'lja va yirtqichning mavjudligi va o'zaro barqarorligini ko'rsatadi; Agar populyatsiyalar shu nuqtaga yaqinlashsa, ular o'zaro ta'sir orqali tabiiy muvozanatga keladi, bu esa ekologik barqarorlikdir.

XULOSA

Populyatsiya jarayonlarini modellashtirish — bu zamonaviy tabiiy fanlar sohasida muhim ilmiy yo'nalishlardan biridir. Tabiatdagi murakkab biologik tizimlarni chuqur tahlil qilish va ularning xatti-harakatlarini matematik usullar orqali tushuntirish, ekologiya, biologiya va boshqa sohalarda samarali ilmiy yechimlar yaratishga xizmat qiladi. Lotka–Volterra modeli aynan shunday muammolarga samarali javob beradi[1]. U yirtqich va o'lja populyatsiyalari o'rtasidagi o'zaro ta'sirni matematik tenglamalar yordamida ifodalaydi va ularning vaqt o'tishi bilan qanday o'zgarishini grafik tarzda ko'rsatadi. Model biologik tizimlarning muvozanati va murakkab dinamikasini tushunishda asosiy nazariy poydevor hisoblanadi. Zamonaviy hisoblash texnologiyalari va grafik vositalari yordamida 3D rangli grafiklar yaratish imkoniyati biologik tizimlarning harakatini yanada intuitiv va aniq ko'rishga yordam beradi. Bu grafiklar o'lja va yirtqich populyatsiyalarining vaqtga bog'liq o'zgarishini, ularning o'sish va kamayish sikllarini, shuningdek o'zaro ta'sir intensivligini ranglar va shakllar orqali vizual tarzda ifodalaydi. Natijada murakkab jarayonlarni oddiy ko'rinishda tahlil qilish va kelajakdagi populyatsiya holatlarini ishonchli prognoz qilish osonlashadi. Shu bilan birga, Lotka–Volterra modeli faqat biologiya bilan cheklanmay, ekologik monitoring, epidemiologiya, iqtisodiyot va tizimli tahlil kabi ko'plab zamonaviy fanlar va amaliy sohalarda qo'llanilmoqda. Bu model fundamental ilmiy muammolarni yechishda muhim vosita bo'lib, murakkab tizimlarning xatti-harakatini tushuntirishda asosiy rol o'ynaydi.

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IKKI KARRA NOCHIZIQLI MANBA EGA NODIVERGENT KO'RINISHDAGI PARABOLIK TENGLAMALAR ORQALI TAVSIFLANUVCHI ISSIQLIK TARQALISH MASALASINING YECHIM XOSSALARI

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$Q = \{(x, t): x \in R^N, t > 0\}$ sohada manba hadi va o'zgaruvchan zichlikni o'z ichiga olgan, nodivergent ko'rinishdagi nochiziqli parabolik diffuziya tenglamasini qaraymiz:

$$|x|^{\alpha_1} \frac{\partial u}{\partial t} = u^{\beta} \frac{\partial}{\partial x} \left(|x|^{\alpha_2} u^{m-1} \left| \frac{\partial u}{\partial x} \right|^{p-2} \frac{\partial u}{\partial x} \right) + |x|^{\alpha_1} u^q \quad (1)$$

boshlang'ich shartlar bilan

$$u(x, t)|_{t=0} = u_0(x) \geq 0, x \in R, \quad (2)$$

Bu yerda $\beta < 1, m \geq 1, p \geq \max\{2, \alpha_2 - \alpha_1\}, q > 1, \alpha_1 < 0, \alpha_2 < 0$ sonli parametrlar bo'lib, $u_0(x)$ uzluksiz, manfiy bo'lmagan, chegaralangan funksiyadir.

1-Teorema. Agar quyidagi shartlardan kamida bittasi bajarilsa

$$\alpha_1 < -1, \mu_1 > \mu_2, \text{ yoki } \alpha_1 = -1, \mu_1 > 1,$$

hamda

$$y(x, t) \leq y_+(x, t), x \in R,$$

munosabat o'rinni bo'lsa, u halda Q sohada (4), (5) masalaning global umumlashgan yechimi mavjud bo'ladi va u quyidagi bahoni qanoatlantiradi

$$y(x, t) \leq y_+(x, t) = t^{-n_1} \bar{g}(\eta). \quad (12)$$

Bu yerda

$$\mu_1 = \frac{q - \beta}{1 - \beta}, \mu_2 = \frac{m + p - 2}{1 - \beta} + \frac{p - \alpha_2 + \alpha_1}{\alpha_1 + 1}$$

bo'lib, μ_2 – Fujita tipidagi kritik eksponent hisoblanadi.

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BIOLOGIK POPULYATSIYA JARAYONLARINI MATEMATIK MODELLASHTIRISH, AVTOMODEL YECHIMLAR QURISH VA YECHIM ASIMPTOTIKALARI

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Bu model Fisher–KPP modelining nolinear diffuziya bilan umumlashgan ko‘rinishi hisoblanadi

$$\frac{\partial u}{\partial t} = \frac{\partial}{\partial x} \left(u^\sigma \frac{\partial u}{\partial x} \right) + ku(1-u) \quad (1)$$

$$u(x, 0) = u_0(x) \quad (2)$$

(1)-(2) masalani yechish uchun:

$$\frac{d\bar{u}}{dt} = k\bar{u}(1-\bar{u}) \quad (3)$$

(3) tenglamani yechib, $\bar{u} = \frac{Ce^{kt}}{1 + Ce^{kt}}$ topamiz. Keyingi qadamda chiziqli ajratish usulidan foydalanib, yechimni quyidagi ko‘rinishga qidiramiz:

$$u(x, t) = \bar{u}w(\tau, x) \quad (4)$$

Bu yerda $\tau = \tau(t)$ vaqtda bog‘liq funksiya. (4) ni (1) tenglamaga qo‘yamiz va w nisbatan quyidagi tenglamaga kelimiz:

$$\frac{\partial w}{\partial \tau} = \frac{\partial}{\partial x} \left(w^\sigma \frac{\partial w}{\partial x} \right) + k\bar{u}^{1-\sigma} w(1-w) \quad (5)$$

$$\tau(t) = \int \bar{u}^{-\sigma} dt = \frac{(1 + e^{kt})^{1-\sigma}}{k(1-\sigma)}. \quad t \rightarrow \infty, \bar{u}^{1-\sigma} \rightarrow 1$$

$$\frac{\partial w}{\partial \tau} = \frac{\partial}{\partial x} \left(w^\sigma \frac{\partial w}{\partial x} \right) + kw(1-w)$$

Keyingi qadamda $w(\tau, x) = f(\xi)$, $\xi = \frac{|x|}{\tau^n}$ ko‘rinishda qidiramiz va avtomodel tenglamaga kelimiz:

$$\frac{d}{d\xi} (f^\sigma f') + \frac{1}{2} \xi f' + kf(1-f) = 0 \quad (6)$$

(7) tenglama uchun quyidagi shartlarni qo‘yamiz:

$$f(0) = M, f(d) = 0, 0 < d < \infty, f(\xi) \geq 0 \quad (7)$$

$f(0) = M$ sharti biologik avtomodel yechimning markazdagi qiymatini beradi:

$\xi = 0 \Rightarrow f(0) = M$ bu yerda M – markazdagi maksimal yoki berilgan zichlik qiymati.

Foydalanilgan adabiyot

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2. Aripov, M., & Sadullaeva, S. Computer simulation of nonlinear diffusion processes. Tashkent, National University Press., (2020), pp.450-459.

CHIZIQSIZ CHEGARAVIY SHARTLI PARABOLIK SISTEMALAR YECHIMLARINING SIFAT XOSSALARI

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Biz ushbu maqolada $Q_+ = \{(x, t) : x \in R_+^N, 0 < t < T\}$ sohada quyidagi masalani qaraymiz:

$$\begin{cases} u_{it} = \nabla \left(|\nabla u_i^{m_i}|^{p_i} \nabla u_i^{m_i} \right), & x \in R_+^N, 0 < t < T, \\ -|\nabla u_i^{m_i}|^{p_i} \frac{\partial u_i^{m_i}}{\partial x_1} = u_{i+1}^{q_i}, & u_{k+1} = u_1, x_1 = 0, 0 < t < T, \\ u_i(x, 0) = u_{i0}(x), & x \in R_+^N, \end{cases} \quad (1)$$

bunda m_i, p_i nochiziqli muhit xususiyatlarini ifodalovchi sonli parametrlar va quyidagi shartga ega: $p_i > \frac{1}{m_i} - 1, m_i > 1, q_i > 0, p_i > 0$. $u_{i0}(x)$ - uzluksiz, manfiy bo'lmagan, chegaralangan

funksiyalar. Ular quyidagi shartlarini qanoatlantiradi: $-|\nabla u_{i0}^{m_i}|^{p_i} \frac{\partial u_{i0}^{m_i}}{\partial x_1} = u_{(i+1)0}^{q_i}, x_1 = 0$, va ba'zi $x_0 \in R_+^N$ nuqta uchun $\sup p u_{i0} \subset B_R(x_0) \cap R_+^N, u_{i0} \neq 0$ bo'ladi.

Teorema. Agar $p_i > \frac{1}{m_i} - 1, m_i > 1$ shartlar bajarilsa, u holda avtomodel tenglamaning

kompakt tashuvchiga ega yechimlari $\eta_i \rightarrow \left(\frac{a_i}{b_i} \right)^{\gamma_1}$ da quyidagi asimptotikaga ega bo'ladi:

$$h_i(\eta_i) = \bar{h}_i(\eta_i)(1 + o(1)), \quad (3)$$

bu yerda $\bar{h}_i(\eta_i) = (a_i - b_i \eta_i^{\gamma_1})^{\gamma_2}$ belgilangan.

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NODAVRIY, SOZLANUVCHAN OPTIK SHAFFOFLIKKA EGA, KO'P QATLAMLI TIO₂-ZNO TUZILMALARI YORDAMIDA ULTRABINAFSHA NURLANISHDAN HIMOYA

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Kirish

Atrof-muhitdagi ultrabinafsha (UB) nurlanishining polimerlar, qurilish materiallari va biologik tizimlarga zararli ta'siri tufayli samarali UB ekranlarini yaratish dolzarb vazifa hisoblanadi. TiO_2 va ZnO kabi keng polosali yarimo'tkazgichlar o'zlarining yuqori fotobarqarorligi bilan ajralib turadi. Biroq, ularni quyosh nuri ostida shaffof saqlash va nurlanishni qaytarish darajasini boshqarish murakkab texnik jarayondir. Ushbu ishda nodavriy ko'p qatlamli tuzilmalar orqali ko'rinuvchi sohadagi shaffoflikni kamaytirmasdan, UB nurlanishini samarali to'sish muammosi hal qilingan [1,3].

1.Eksperimental metodologiya

1.1. Sintez jarayoni: Qoplamalar BK7 shishasi va Si (100) substratlarida (p-turdagi SSP (bir tomonlama sayqallangan plastinka)) 250°C haroratda atom qatlamining cho'kishi (ALD) usulida o'stirildi. Titan dioksidi (TiO_2) uchun tetrakis(dimetilamido)titan (TDMAT) va rux oksidi (ZnO) uchun dietilrux (DEZ) prekursor sifatida qo'llanildi.

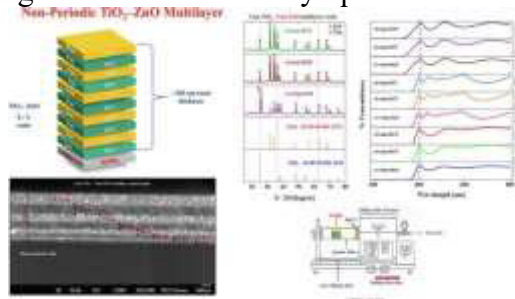
1.2. Nodavriy dizayn: Qatlamlar qalinligi tub sonlar ketma-ketligiga (2, 3, 5, 7, 11, 13, 17, 19, 23 nm) asoslangan holda taqsimlandi. Bunday nodavriy arxitektura ma'lum to'lqin uzunliklarida rezonansli interferensiyani yuzaga keltirib, optik filtr vazifasini bajaradi [1,2].

2.Natijalar va tahlil

2.1. Optik xususiyatlar: Spektroskopik ellipsometriya tahlillari ko'p qatlamli tizimlarning sindirish ko'rsatkichi (n) va yutilish koeffitsiyenti (k) qiymatlarini aniqlash imkonini berdi. 5 nm TiO_2 /1 nm ZnO konfiguratsiyasiga ega namuna eng yuqori indeks modulyatsiyasini namoyon etdi.

2.2. Termik barqarorlik: RTP jarayonidan so'ng namunalar rentgen difraksiyasi (XRD) orqali tekshirildi. 500°C haroratda 20 daqiqa davomida qizdirish ZnO ning (002) tekisligi bo'yicha kristallanishini oshirdi, biroq qatlamlararo diffuziya cheklangan bo'lib qoldi, bu esa strukturaning yaxlitligini tasdiqlaydi.

2.3. UB-himoya samaradorligi: Barcha namunalar 400–800 nm to'lqin uzunligi oralig'ida 90% dan yuqori optik shaffoflikni saqlab qoldi. UB-B (280–315 nm) va UB-A (315–400 nm) diapazonlarida nurlanishning o'tishi 5% dan past ko'rsatkichni tashkil etdi. Bu ko'rsatkich an'anaviy bir qatlamli qoplamalarga nisbatan 2 barobar yuqori samaradorlikni anglatadi [1].



1-rasm. Nodavriy TiO_2 – ZnO ko'p qatlamli tuzilmasi.

Xulosa

Tadqiqot natijalari shuni ko'rsatadiki, ALD usulida olingan nodavriy TiO_2 – ZnO ko'p qatlamli tuzilmalari yuqori shaffoflik talab qilinadigan sohalarda (masalan, aqlli oynalar va kosmik datchiklar) ideal UB himoya materiali bo'la oladi. Tub sonlar ketma-ketligiga asoslangan nodavriy dizayn an'anaviy foton kristallariga nisbatan kengroq spektral diapazonda ishlash imkonini beradi [1,3].

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POLIMER ASOSIDAGI AMORF TiO_2 QATLAMINI IMPULS-DAVRIYLI LAZER YORDAMIDA KRISTALLASH

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Kirish

Titan dioksidi (TiO_2) o'zining yuqori sindirish ko'rsatkichi, kimyoviy barqarorligi va ajoyib fotokatalitik xususiyatlari tufayli zamonaviy texnologiyalarda keng qo'llaniladi. So'nggi yillarda moslanuvchan (flexible) substratlarda, xususan polietilentereftalat (PET) yoki polimid (PI) kabi polimerlarda yuqori sifatli kristall TiO_2 qatlamlarini olishga bo'lgan qiziqish ortib bormoqda. Biroq, TiO_2 ning amorf holatdan kristal (anataz) holatiga o'tishi uchun kamida $350 - 450^\circ\text{C}$ harorat talab etiladi, bu esa polimer substratlarning erish haroratidan yuqoridir.

Lazerli kristallash (LC) usuli ushbu muammoni hal qilishda samarali vosita bo'lib, u material sirtiga juda qisqa vaqt davomida yuqori energiya oqimini yo'naltirishga asoslanadi [1,3].

1.Eksperimental qism

1.1. Namunalar tayyorlash: Amorf TiO_2 qatlamlari (qalinligi~100 nm) polimer substratlarga magnetronli purkash (magnetron sputtering) yoki atom qatlamli cho'ktirish (ALD) usullari orqali xona haroratida cho'ktiriladi.

1.2. Lazerli ishlov berish: Kristallash jarayoni uchun quyidagi parametrlar qo'llaniladi:

- Lazer turi: Turli quvvatdagi mis bug'laridagi lazerlar (MBL), o'rtacha quvvati mos ravishda 1 va 10 Vt, MBL ning ikkinchi garmonikasi ($\lambda=255,3 \text{ nm}$).
- Impuls davomiyligi: 20 ns, maksimal quvvat 10^5 Vt .

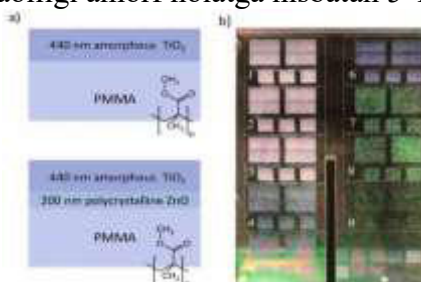
Lazer nurlanishining to'liq uzunligi TiO_2 ning yutilish chegarasiga mos kelishi shart, bu energiyaning faqat plyonka tomonidan yutilishini va polimer substratga minimal issiqlik o'tishini kafolatlaydi [1,3].

2.Natijalar va muhokama

2.1. Strukturaviy o'zgarishlar: Rentgen difraksiyasi (XRD) va Raman spektroskopiyasi tahlillari lazer energiyasi oshishi bilan amorf fon yo'qolib, anataz fazasiga xos bo'lgan cho'qqi paydo bo'lishini ko'rsatadi. Energiya zichligi kritik nuqtadan ($> 120 \text{ mJ/cm}^2$) oshganda, material rutil fazasiga o'ta boshlaydi yoki polimer substratda termik degradatsiya (shishish) kuzatiladi.

2.2. Morfologiya: Skanerlovchi elektron mikroskopiya (SEM) tasvirlari shuni ko'rsatadiki, lazer nuri ta'sirida plyonka sirti zichlashadi va kristall donachalar (grains) hajmi kattalashadi. Lazer parametrlarini optimallashtirish orqali sirt g'adir-buduriligini (roughness) minimal darajada saqlash mumkin.

2.3. Optik va elektr xossalari: Kristallashdan so'ng TiO_2 qatlamining optik o'tkazuvchanligi ko'rinuvchi sohada 80-85% gacha saqlanib qoladi. Shu bilan birga, kristall faza hosil bo'lishi hisobiga materialning fotokatalitik faolligi amorf holatga nisbatan 5-10 barobar ortadi [1,2].



1-rasm. a) Lazer nurlanishidan oldin ko'ndalang kesimdagi "cho'ktirilgan" namunalarning sxemasi; b) Namuna sifatida olingan namunaning fotosurati. Lazer dog'lari $0,5 \times 0,5 \text{ sm}^2$ (yoki $1 \times 1 \text{ sm}^2$) o'lchamdagi yorqin kvadratik mintaqalar sifatida ko'rinadi.

Xulosa

Ushbu ishda lazerli kristallash texnologiyasi polimer substratlardagi TiO_2 plyonkalarining xossalarini yaxshilashda an'anaviy termik usullarga samarali muqobil ekanligi isbotlandi. Nanosekundli impulsar substratning yaxlitligini buzmaganda yuqori darajadagi kristallikni ta'minlaydi. Bu texnologiya kelajakda moslanuvchan quyosh panellari, o'zi tozalanuvchi yuzalar va sensorlar ishlab chiqarishda muhim o'rin tutadi [1,3].

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PLAZMA BILAN KUCHAYTIRILGAN ZnO/TiO_2 KOMPOZITLARINI SINTEZ QILISH VA TAVSIFLASH

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Fotokataliz jarayoni atrof-muhitni tozalash, xususan, suvdan organik ifloslantiruvchi moddalarni yo'qotishda muhim ahamiyatga ega. TiO_2 va ZnO yarimo'tkazgichlari o'zlarining mos energetik zonalari va yuqori barqarorligi tufayli eng ko'p o'rganilayotgan materiallardir. Biroq, ularning samaradorligini yanada oshirish uchun materialning sirt maydonini kengaytirish va yorug'likni yutilishini optimallashtirish talab etiladi.

Invers opal (IO) strukturalari — bu tartibli joylashgan makrog'ovakli materiallar bo'lib, ular yorug'likning "sekin foton" (slow photon) effekti orqali material ichida ko'p marotaba akslanishi va yutilishini ta'minlaydi [1,2].

1. Eksperimental qism

1.1. Invers opal karkasini tayyorlash: Dastlab polistirol (PS) sferalaridan iborat opal matritsasi o'z-o'zidan yig'ilish (self-assembly) usulida tayyorlandi. So'ngra ushbu matritsa karkas sifatida ishlatildi.

1.2. PE-ALD sintezi: Qatlamlarni cho'ktirish uchun plazma bilan kuchaytirilgan atom qatlamli cho'ktirish usuli qo'llanildi:

- TiO_2 uchun: Tetrakis(dimetilamido)titan (TDMAT) va kislorod plazmasi.
- ZnO uchun: Dietilruks (DEZ) va kislorod plazmasi.
- Jarayon: PS sferalari orasidagi bo'shliqlar atom qatlamli cho'ktirish (ALD) orqali to'ldirildi, so'ngra polimer matritsa termik yo'l bilan chiqarib tashlanib, invers opal strukturasi hosil qilindi. Ikkinchi yarimo'tkazgich qatlami hosil bo'lgan IO devorlariga yupqa parda shaklida o'stirildi [1].

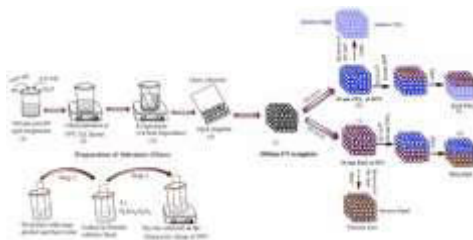
2. Natijalar va tahlil

2.1. Strukturaviy tavsif: Skanerlovchi elektron mikroskopiya (SEM) tasvirlari asali uyusiga o'xshash, geksagonal tartibdagi makrog'ovakli strukturani tasdiqladi. G'ovaklarning o'rtacha diametri 250-300 nm ni tashkil etdi.

2.2. Fotokatalitik faollik: Metilen ko'ki (MB) bo'yog'ining parchalanishi misolida o'tkazilgan testlar shuni ko'rsatdiki:

- ZnO/TiO_2 IO kompoziti oddiy bir qatlamli plyonkalarga nisbatan 4 barobar yuqori faollik ko'rsatdi.

• Bu samaradorlik yarimoʻtkazgichlar orasidagi II-tur geterobirika (type-II heterojunction) hosil boʻlishi bilan izohlanadi, bunda elektronlar ZnO dan TiO_2 ga oʻtadi va rekombinatsiya ehtimoli kamayadi [1,2].



1-rasm. TiO_2 , ZnO va kompozit teskari opallarning sintezining sxematik koʻrinishi: PS nanosferalaridan tartiblangan mikrogʻovakli tuzilmalargacha.

Xulosa

Ushbu tadqiqot PE-ALD usuli yordamida murakkab 3D nanostrukturalarni — invers opallarni sintez qilish imkoniyatini koʻrsatib berdi. TiO_2 va ZnO ning kombinatsiyasi hamda invers opalning fotonik xususiyatlari birlashishi natijasida Quyosh energiyasidan foydalanish samaradorligi keskin oshdi. Ushbu turdagi kompozitlar kelajakda suvni tozalash tizimlari va vodorod energetikasida (suvni fotoliz qilish) keng qoʻllanilishi mumkin [1,2].

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TiO_2/ZnO NANOSTRUKTURALARINI QATTIQ HOLATDA DISPERSIYA VA GIDROTERMAL SINTEZ QILISH

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Kirish

Sanoat oqova suvlari tarkibidagi organik boʻyoqlar atrof-muhit va inson salomatligi uchun jiddiy xavf tugʻdiradi. Rodamin B (RhB) toʻqimachilik va qogʻoz sanoatida keng qoʻllaniladigan barqaror organik birikma boʻlib, uni anʼanaviy usullar bilan tozalash qiyin. TiO_2 va ZnO yarimoʻtkazgichlari oʻzlarining arzonligi va yuqori oksidlovchi xususiyati tufayli fotokatalizda yetakchi hisoblanadi. TiO_2/ZnO geterobirikmalarini yaratish orqali elektron-kovak juftliklarining rekombinatsiyasini kamaytirish va fotokatalitik samaradorlikni oshirish mumkin.

1. Eksperimental qism

1.1. Katalizator sintezi:

• Qattiq holatdagi dispersiya: Titan izopropoksidi va rux atsetati asosiy xomashyo sifatida ishlatildi. Sol-gel jarayonidan soʻng olingan kukunlar turli haroratlarda (450 – 650°C) kalsinatsiya qilindi.

• Gidrotermal usul: Reaksiya aralashmasi avtoklavda yuqori bosim va harorat ostida saqlanib, nanostrukturalarning kristallik darajasi oshirildi.

2. Natijalar va tahlil

2.1. Tavsiflash (Characterization):

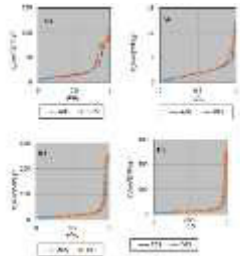
• XRD natijalari: TiO_2 ning anataz fazasi va ZnO ning vursit (wurtzite) strukturalari mavjudligi tasdiqlandi. Kristallar oʻlchami Debay-Sherrer formulasi boʻyicha hisoblandi.

• FE-SEM tahlili: Nanostrukturalarning sirt morfologiyasi sferik va tayoqchasimon shakllar aralashmasidan iborat ekanligini koʻrsatdi.

• BET tahlili: TiO_2/ZnO kompozitining solishtirma sirt maydoni sof oksidlarga qaraganda yuqori ekanligi va bu adsorbsiya jarayonini tezlashtirishi aniqlandi.

2.2. Fotokatalitik faollik: Eng yuqori degradatsiya samaradorligi quyidagi sharoitlarda kuzatildi:

- RhB boshlang'ich konsentratsiyasi: 10 mg/L;
- Katalizator dozasi: 0,8 g/L;
- pH qiymati: 7 (neytral muhit).



1-rasm. S2, S6, H2 va H3 namunalarining N_2 adsorbsiyasi/desorbsiyasi izotermasi.

Natijalar shuni ko'rsatdiki, gidrotermal usulda olingan namunalar yuqori kristallik va sirt maydoni hisobiga RhB ni 120 daqiqa ichida 98% gacha parchalashga muvaffaq bo'ldi.

Xulosa

Ushbu tadqiqot TiO_2/ZnO nanostrukturalarini sintez qilishning samarali usullarini va ularning fotokatalitik imkoniyatlarini ko'rsatib berdi. TiO_2 va ZnO ning sinergik ta'siri nurlanish ostida zaryad tashuvchilarning samarali ajralishini ta'minladi. Ushbu material oqova suvlarni organik bo'yoqlardan tozalashda arzon va samarali texnologiya sifatida tavsiya etiladi.

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BARQAROR FOTONIK QURILMALAR UCHUN TiO_2 NANOSTRUKTURALARIDA GARMONIKA HOSIL QILISH ORQALI MODULYATSIYALASH

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Kirish

Titan dioksidi (TiO_2) o'zining keng taqiqlangan zonasi, yuqori sindirish ko'rsatkichi va ajoyib kimyoviy-termik barqarorligi tufayli optoelektronika va fotonika sohasida eng ko'p o'rganilayotgan n-turdagi yarimo'tkazgichlardan biridir. So'nggi yillarda axborotni optik qayta ishlash, lazer texnikasi va optik kommutatsiya qurilmalarida qo'llash uchun materiallarning nanochiziqli optik (NLO) xususiyatlarini, xususan, garmonika hosil qilish effektlarini boshqarish dolzarb vazifaga aylandi.

Pirolitik purkash (spray pyrolysis) usuli sanoatda keng miqyosda yupqa qatlamlar olish uchun tejamkor va qulay texnologiya hisoblanadi. Ushbu ishda ilk bor prekursor eritmasining molyarligini o'zgartirish orqali TiO_2 qatlamlarining strukturaviy mukammalligi va uchinchi tartibli nanochiziqli optik sezgirliги ($\chi^{(3)}$) o'rtasidagi fundamental bog'liqlik tizimli ravishda tadqiq etildi [1,2].

1.Eksperimental qism

1.1. Yupqa qatlamlar sintezi: TiO_2 yupqa qatlamlari tozalangan shisha substratlarda 400°C haroratda pirolitik purkash usuli bilan olindi. Prekursor eritmasini tayyorlash uchun titan

tetraizopropoksidi (TTIP) atsetilatseton va etanolda eritildi. Prekursorning molyar konsentratsiyasi quyidagicha o'zgartirildi: 0,05 M; 0,10 M; 0,15 M; 0,20 M.

Purkash tezligi (spray rate) va datchik dumi orasidagi masofa barcha eksperimentlarda doimiy saqlangan.

2.Natijalar va muhokama

2.1. Strukturaviy va morfologik tahlil (XRD va SEM): XRD difraktogrammalari barcha namunalarda anataz fazasiga mos keluvchi (101), (004) va (200) tekisliklarining yaqqol akslanishini ko'rsatdi. Molyarlik 0,05 M dan 0,2 M gacha oshganda, anataz fazasiga xos bo'lgan cho'qqining intensivligi keskin ortdi va yarim balandlikdagi kengligi kamaydi. Bu holat kristallit o'lchamining 18 nm dan 29 nm gacha o'sganidan dalolat beradi. SEM tasvirlari esa konsentratsiya ortishi bilan sirt daryosimon strukturadan yanada zich va tekis nanodonachali morfologiyaga o'tganini ko'rsatdi.

2.2. Chiziqli optik xususiyatlar: UV-Vis yutilish spektrlaridan foydalanib, Tauts (Tauc) tenglamasi orqali to'g'ri taqiqlangan zona kengligi (E_g) hisoblandi. Konsentratsiya 0,05 M dan 0,2 M gacha oshganda, taqiqlangan zona kengligi 3,25 eV dan 3,12 eV gacha kamaydi. Bu qizil siljish (red shift) kristallit o'lchamining kattalashishi va ichki kuchlanishlarning (strain) kamayishi bilan bog'liq.

2.3. Ninochiziqli optik (NLO) xossalari va garmonika hosil bo'lishi: Uchinchi garmonika hosil bo'lishi (THG - Third Harmonic Generation) va ninochiziqli yutilish koeffitsiyenti (β) Z-skanerlash (Z-scan) texnikasi yordamida, 532 nm to'lqin uzunligidagi impulsli lazer nurlanishi ostida o'rganildi.

- Yopiq diafragma (closed-aperture) Z-scan egri chiziqlari materialning manfiy ninochiziqli sindirish ko'rsatkichiga (o'z-o'zidan defokuslanish effekti) ega ekanligini ko'rsatdi.

- Ochiq diafragma (open-aperture) tahlillar ikki fotonli yutilish (two-photon absorption) jarayoni mavjudligini tasdiqladi.

- Prekursor konsentratsiyasi 0,15 M bo'lgan namuna eng yuqori ninochiziqli sezgirlik ko'rsatkichini ($\chi^{(3)} \approx 10^{-11}$) namoyon etdi. Bu ko'rsatkich yuqori optik barqarorlik talab etiladigan datchik va modulyatorlar uchun juda mos keladi [1].

Xulosa

Tadqiqot pirolitik purkash usulida prekursor eritmasi konsentratsiyasini muhandislik qilish orqali TiO₂ plyonkalarining optik va ninochiziqli parametrlarini muvaffaqiyatli boshqarish mumkinligini isbotladi. Anataz fazasining kristallik darajasi va garmonika hosil qilish samaradorligi o'rtasidagi bog'liqlik aniqlandi. Olingan natijalar 0,15 M li TiO₂ kompozitsiyasini kelajakda yashil va barqaror fotonika, optik datchiklar hamda yuqori tezlikdagi kommutatsiya tizimlarida qo'llash uchun asosiy material sifatida tavsiya etish imkonini beradi [1,2].

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M.INTERVAL KOEFFITSIYENTLI CHIZIQLI DASTURLASH MASALASINI YECHISH ALGORITMI VA DASTURIY TA'MINOTI

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Annotatsiya. Ushbu maqolada interval koeffitsiyentli chiziqli dasturlash masalalarini yechish uchun algoritm ishlab chiqilgan va uning dasturiy ta'minoti tuzilgan. Taklif etilgan algoritm klassik simpleks usuli va interval arifmetika yondashuvini uyg'unlashtirib, koeffitsiyentlarning

barcha mumkin bo'lgan qiymatlari uchun optimal hamda turg'un yechimni aniqlash imkonini beradi.

Hozirgi kunda real hayotdagi ko'plab iqtisodiy, muhandislik va boshqaruv masalalari optimallashtirish masalalari sifatida ifodalanadi. Bu masalalarning aksariyatida kirish ma'lumotlari koeffitsiyentlar, cheklovlar va maqsad funksiyalari aniq son qiymatlarga ega bo'lmaydi. Bunday noaniqlik ko'plab sabablar bilan bog'liq: o'lehash xatoliklari, ma'lumotlarning to'liq emasligi, tashqi muhitning o'zgaruvchanligi yoki kelajakdagi holatlarga nisbatan bashorat qilish zarurligi.

Interval arifmetika — bu noaniqliqni ifodalashning eng tabiiy va keng qo'llaniladigan usullaridan biri hisoblanadi.

Interval koeffitsiyentlar $[a^-, a^+]$ shaklida beriladi, ya'ni koeffitsiyentning aniq qiymati noma'lum, lekin u ma'lum oraliqda yotishi kafolatlanadi. Bu yondashuv ehtimollik usullardan farqli ravishda ehtimollik taqsimotini bilishni talab qilmaydi [1].

Interval koeffitsiyentli chiziqli dasturlash masalasi umumiy ko'rinishda quyidagicha ifodalanadi:

$$\max Z = [c]^T x \quad (1)$$

$$[A]x \leq [b], x \geq 0 \quad (2)$$

Interval koeffitsiyentli vektori va cheklov matritsasi quyidagicha beriladi:

$$[c] = ([c_i^-, c_i^+]) \in \mathbb{R}^n \quad (3)$$

$$[A] = ([a_{ij}^-, a_{ij}^+]) \in \mathbb{R}^{m \times n} \quad (4)$$

Interval koeffitsiyentli chiziqli dasturlash masalasining markaziy (nominal) masalasi – barcha intervallarning markaz qiymatlari bilan tashkil topgan klassik chiziqli dasturlash masalasidir:

$$\max Z_m = c_m^T x \quad (5)$$

$$A_m x \leq b_m, x \geq 0 \quad (6)$$

Interval koeffitsiyentlarning markaziy qiymatlari quyidagi tengliklar orqali aniqlanadi:

$$c_m = \frac{c^- + c^+}{2} \quad (7)$$

$$A_m = \frac{A^- + A^+}{2}, b_m = \frac{b^- + b^+}{2} \quad (8)$$

Interval koeffitsiyentlarning o'rta qiymatdan chetlashish darajasini ifodalash uchun og'ish operatorlari kiritiladi:

$$\Delta_c = \frac{c^+ - c^-}{2} \quad (9)$$

$$\Delta_A = \frac{A^+ - A^-}{2}, \Delta_b = \frac{b^+ - b^-}{2} \quad (10)$$

Interval chiziqli dasturlash masalalarida optimal yechim topish va uning turg'unligini baholash uchun quyidagi lemma o'rinalidir.

Lemma. Agar x^* — nominal masalaning optimal yechimi bo'lsa, u holda interval maqsad funksiyasining quyi va yuqori qiymatlari quyidagicha baholanadi:

$$Z^- = c_m^T x^* - \Delta_c^T |x^*| \quad (11)$$

$$Z^+ = c_m^T x^* + \Delta_c^T |x^*| \quad (12)$$

Masalaning optimal yechimi x^* barcha mumkin bo'lgan interval tebranishlarda ham o'z kuchini saqlab qolishi uchun zarur va yetarli shart quyidagi tengsizlik orqali ifodalanadi [2]:

$$A_m x^* + \Delta_A |x^*| \leq b_m - \Delta_b \quad (13)$$

Yechimning ishonchlilik va parametrik o'zgarishlarga bardoshlilik darajasini baholash, bazaviy turg'unlik chegaralarini aniqlashda barqarorlik ko'rsatkichlaridan foydalaniladi [3,4]. Maqsad funksiyasi uchun esa quyidagi *ishonchlilik indeksi* hisoblanadi.

$$RI = \left(1 - \frac{z^+ - z^-}{2|z_m|} \right) \times 100\%$$

Ishlab chiqilgan algoritm noaniq va o'zgaruvchan real iqtisodiy-muhandislik muhitida eng ma'qul, risk darajasi hisoblangan qarorlarni qabul qilishda an'anaviy chiziqli dasturlash usullariga qaraganda yuqori samaradorlik ko'rsatadi. Shuningdek, boshlang'ich interval masalani yechish, og'ish matritsalarini tahlil qilish va turg'un yechimni baholashdan iborat. Algoritm asosida yaratilgan dasturiy ta'minot chiziqli dasturlash masalasini barcha interval oraliqlarda tahlil qilib, ishonchli yechimlar sohasini vizual ko'rinishda shakllantiradi.

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О ЛОКАЛЬНЫХ МИНИМУМАХ ДЗЕТА-ФУНКЦИИ ЭПШТЕЙНА

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Оптимальные решетки, соответствующие положительно определенным квадратичным формам, — это решетки, обеспечивающие максимальную плотность упаковки шаров в евклидовом пространстве заданной размерности. Эти решетки связаны с экстремальными положительно определенными квадратичными формами, у которых отношение минимума формы к ее дискриминанту максимально (т.е. решается задача о наименьшем значении плотности или нахождении плотнейшей упаковки).

Положительно определенная квадратичная форма

$$f = f(\beta) = f(\beta_1, \beta_2, \dots, \beta_n) = \sum_{i,j=1}^n a_{ij} \beta_i \beta_j$$

(где все угловые миноры матрицы положительны) соответствует решетке, если ее минимум $m(f)$ (минимальное значение на ненулевых целочисленных векторах) достаточно велик при заданном определителе матрицы $d(f)$. Оптимальной считается форма, максимизирующая значение $\frac{m(f)}{\sqrt[n]{d(f)}}$.

Задача нахождения оптимальных решеток сводится к изучению "предельных" (крайних) положительно определенных квадратичных форм.

Квадратичная форма называется положительно определенной, если все ее значения при вещественных значениях переменных (не равных нулю) положительны. Для этого необходимо и достаточно, чтобы все угловые миноры ее матрицы были строго положительны.

Пусть

$$f = f(\beta) = f(\beta_1, \beta_2, \dots, \beta_n) = \sum_{i,j=1}^n a_{ij} \beta_i \beta_j$$

положительно определенная квадратичная форма с вещественными коэффициентами $a_{ij} = a_{ji}$, определителем $d = d(f) = \det(a_{ij}) > 0$.

Пусть s - комплексное число, рассмотрим дзета функцию Эпштейна $Z(f, s)$, задаваемую при $\operatorname{Re} s > 1$ рядом

$$Z(f, s) = \sum_{x \neq 0} \{f(\beta)\}^{-\frac{ns}{2}}$$

суммирование здесь и далее ведется по всем целым векторам $\beta = (\beta_1, \beta_2, \dots, \beta_n)$ за исключением $0 = (0, 0, \dots, 0)$. При вещественном $s > 0$ функция $Z(f, s)$ вещественна.

Фиксируем вещественное число $s > 0, s \neq 1$ и для данного вещественного числа $d_0 > 0$ рассмотрим $Z(f, s)$ как функцию от формы точки $f = (a_{11}, a_{22}, \dots, a_{nn}, a_{12}, \dots, a_{n-1n})$, заданную на дискриминантной поверхности P_{d_0} конуса положительности $\mathbb{R}^{\mathbb{N}}$, пространства

коэффициентов $\mathbb{R}^{\mathbb{K}}, \mathbb{N} = \frac{n(n+1)}{2}$. Будем говорить, что форма f_0 определителя $d(f_0) = d_0$ является экстремальной, если f_0 есть точка локального минимума функции $Z(f, s)$ на поверхности P_{d_0} , при данном s , т. е. если в $\mathbb{R}^{\mathbb{K}}$ найдется такая окрестность u_{f_0} , точки f_0 , что

$$Z(f, s) - Z(f_0, s) > 0$$

если $f \in P_{d_0} \cap u_{f_0}$.

Особые интерес представляет отыскание минимума функции $Z(f, s)$, когда $s = 2m, m \in \mathbb{N}$. Этом случае, с помощью матрице положительно определенных квадратичных форм найдется оптимальную решетку кубатурных формул. +

Основным результатом работы является следующее утверждение.

Теорема. Квадратичные формы

$$f(\beta_1, \dots, \beta_5) = \sum_{i=1}^5 \beta_i^2 + \beta_1\beta_2 + \beta_1\beta_3 + \dots + \beta_4\beta_5,$$

$$g(\beta_1, \dots, \beta_5) = f(\beta_1, \dots, \beta_5) - \beta_1\beta_2,$$

$$h(\beta_1, \dots, \beta_5) = f(\beta_1, \dots, \beta_5) - \frac{1}{2}(\beta_1\beta_2 + \beta_3\beta_4 + \beta_3\beta_5 + \beta_4\beta_5)$$

являются локально экстремальными для всех $s > 0, s \neq 1$.

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КОЛИЧЕСТВО ОПЕРАЦИЙ ПРИ ВЫПОЛНЕНИИ БИНАРНОГО АЛГОРИТМА ПОИСКА

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Рассматривается вопрос о количестве операций, которые выполняются на компьютере при определении в одномерном числовом массиве $\text{float } A[n] = \{a_1, a_2, a_3, \dots, a_i, \dots, a_n\}$ элемента, значение которого равно заданному значению key , которое называется ключевым значением. Предполагается, что элементы массива расположены в возрастающем порядке: $a_1 < a_2 < a_3 < \dots < a_i < \dots < a_n$, потому что бинарный алгоритм поиска применяется тогда, когда элементы массива упорядочены, то есть первоначально расположены в возрастающем порядке или в убывающем порядке.

Бинарный алгоритм поиска работает путём сравнения значения срединного элемента a_{mid} массива с заданным ключевым значением key . Если эти значения равны между собой, то элемент массива с заданным ключевым значением найден, им является срединный элемент массива, алгоритм прекращает свою работу. Если же значение срединного элемента не

равно заданному ключевому значению, то искомый элемент массива не найден, бинарный алгоритм поиска рекурсивно повторяется в левом или в правом подмассиве, на которые подразделяется рассматриваемый массив срединным элементом, в зависимости от того, значение срединного элемента массива больше или меньше заданного ключевого значения key . Для определения подмассива, в котором содержится элемент со значением key , необходимо выполнить одну из операций сравнения $a_{mid} > key$ или $a_{mid} < key$. Если $a_{mid} > key$, то это означает, что искомый элемент со значением key содержится в левом подмассиве, если же $a_{mid} < key$, то - в правом подмассиве. В обоих случаях подмассив, в котором не содержится искомый элемент, и срединный элемент a_{mid} исключаются из дальнейшего рассмотрения. И этот процесс сравнения значения срединного элемента подмассива, в котором будет происходить поиск элемента со значением key , подразделения подмассива на две части, если эти значения не равны между собой, продолжается до тех пор, пока не будет найден искомый элемент.

Для определения значения a_{mid} срединного элемента необходимо определить значение его индекса по формуле $I_{mid} = (I_r + I_l) / 2$, где I_{mid} , I_r и I_l , соответственно, значение индекса срединного элемента, правого граничного элемента и левого граничного элемента массива или подмассива, в котором содержится искомый элемент. При определении значения индекса I_{mid} выполняются две арифметические операции (вычитание и деление) и одна операция присваивания. Затем выполняется одна операция сравнения значений a_{mid} и key ($a_{mid} = key$). Если значение a_{mid} не равно key , то срединный элемент не является искомым. В этом случае, как описывалось выше, выполнив ещё три операции (одну из операций сравнения $a_{mid} > key$ или $a_{mid} < key$, и, соответственно, одну пару из операций $r = I_{mid} - 1$ или $l = I_{mid} + 1$) необходимо определить подмассив рассматриваемого массива или подмассива, в котором содержится искомый элемент. Таким образом, при каждом подразделении массива или подмассива на две части, для определения подмассива, содержащего искомый элемент, выполняется 7 операций.

Количество операций, которые выполняются на компьютере при определении элемента, значение которого равно заданному значению key , зависит не только от общего количества элементов массива, но и от их расположения в массиве. Степень сложности алгоритма принято оценивать по наихудшему случаю расположения входных данных относительно поставленной задачи, так как ресурсы, то есть время на выполнение алгоритма и объем памяти компьютера, выделенные для решения задачи в наихудшем случае, будут достаточны для решения задачи в любом другом случае [1-5]. Рассмотрим случай, когда элементы исходного массива расположены таким образом, что искомый элемент будет найден в одном из последних подмассивов исходного массива, содержащего один-единственный элемент.

Вычислим количество подразделений исходного массива и его подмассивов на две части, после которых образуются два подмассива, содержащие по одному-единственному элементу, и один из этих элементов является искомым. После первого подразделения исходного массива, в подмассиве, содержащем искомый элемент, количество элементов равно $n_1 = (n-1)/2$, которое можно представить в виде $n_1 = (n - (2^1 - 1))/2$. После подразделения этого подмассива на две части, в новом подмассиве, содержащем искомый элемент, количество элементов равно $n_2 = (n_1 - 1)/2$, которое можно представить в виде $n_2 = (n - (2^2 - 1))/2^2$. И так далее. Используя метод математической индукции, можно показать, что после выполнения j -того подразделения массива и его возникающих подмассивов на две части, в новом подмассиве, содержащем искомый элемент, количество элементов будет равно $n_j = (n_{j-1} - 1)/2$, которое можно представить в виде $n_j = (n - (2^j - 1))/2^j$. Из соотношения $n_{j_{last}} = (n - (2^{j_{last}} - 1))/2^{j_{last}} = 1$ определяется порядковый номер подразделения исходного массива и соответствующих подмассивов на две части, после которого образуются подмассивы (два подмассива), содержащие по одному-единственному элементу, один из которых является искомым элементом:

$$j_{last} = \log_2(n+1) - 1. \quad (1)$$

Это равенство позволяет сделать вывод, что степень сложности бинарного алгоритма поиска имеет логарифмический вид $O(\log_2 n)$.

После последнего подразделения подмассива на две части, для определения искомого элемента выполняются следующие операции: следуя общим правилам бинарного алгоритма поиска, вычисление индекса срединного элемента подмассива, в котором содержится искомый элемент: $I_{\text{mid}}=0$, потому что в этом подмассиве содержится всего один элемент, $I_r = I_l$; операция сравнения значения элемента подмассива со значением key . Эти значения равны между собой. Искомый элемент, имеющий значение key , найден. Кроме операций, выполненных в процессе подразделения исходного массива и его подмассивов на две части, в конце выполнились 4 операции и обнаружился искомый элемент.

Таким образом, общее количество операций $N(n)$, которые выполняются на компьютере при наихудшем расположении элементов исходного массива по отношению к решаемой задаче, равно

$$N(n)=7*j_{\text{last}}+4=7*[\log_2(n+1)-1]+4=7*\log_2(n+1)-3. \quad (2)$$

Достоверность формул (1) и (2) проверена в практических вычислениях на примере массива $\text{float } A[15]=\{3.1, 3.8, 4.2, 4.9, 5.0, 5.5, 5.7, 6.3, 6.6, 6.9, 7.1, 7.2, 7.3, 7.7, 8.0\}$, в котором количество элементов $n=15$, а искомым элементом является, пусть элемент с заданным значением $\text{key}=7.1$. Количество подразделений данного массива и его подмассивов на две части при поиске искомого элемента бинарным алгоритмом, вычисленное по формуле (1), равно 3: $j_{\text{last}}=\log_2(15+1)-1=\log_2(16)-1=4-1=3$. При практическом поиске в рассмотренном массиве элемента с заданным значением $\text{key}=7.1$ также понадобилось три раза выполнить подразделение массива и его подмассивов на две части. Общее количество операций, которое необходимо выполнить для определения искомого элемента в рассмотренном массиве бинарным алгоритмом, вычисленное по формуле (2), равно 25: $N(15)=7*\log_2(15+1)-3=7*\log_2(16)-3=7*4-3=25$. При практическом поиске элемента с заданным значением $\text{key}=7.1$ общее количество выполненных операций также равно 25, что говорит о достоверности формул (1) и (2).

Достоверность формул (1) и (2) проверена также в практических вычислениях на примере массива $\text{float } B[30]=\{3.1, 3.8, 4.2, 4.9, 5.0, 5.5, 5.7, 6.3, 6.6, 6.9, 7.1, 7.2, 7.3, 7.7, 8.0, 8.1, 8.2, 8.3, 8.8, 9.0, 9.1, 9.4, 9.5, 9.6, 9.7, 9.9, 10.1, 10.3, 10.6, 10.8\}$, в котором количество элементов $n=30$, а искомым элементом является, пусть элемент с заданным значением $\text{key}=10.3$. Количество подразделений данного массива и его подмассивов на две части при поиске искомого элемента бинарным алгоритмом, вычисленное по формуле (1), равно 4: $j_{\text{last}}=\log_2(30+1)-1=\log_2(31)-1=5-1=4$. При практическом поиске в рассмотренном массиве элемента с заданным значением $\text{key}=10.3$ также понадобилось четыре раза выполнить подразделение массива и его подмассивов на две части. Общее количество операций, которое необходимо выполнить для определения искомого элемента в рассмотренном массиве бинарным алгоритмом, вычисленное по формуле (2), равно 32: $N(30)=7*\log_2(30+1)-3=7*\log_2(31)-3=7*5-3=32$. При практическом поиске элемента с заданным значением $\text{key}=10.3$ общее количество выполненных операций также равно 32, что говорит о достоверности формул (1) и (2).

Можно высказать предложения и рекомендации, что при применении бинарного алгоритма поиска можно воспользоваться формулами (1) и (2), получить представление об объёме операций, предстоящих выполнению.

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SOBOLEV FAZOSI $L_2^{(6)}(0,1)$ DA OPTIMAL OSHKORMAS AYIRMALI FORMULA KOEFFITSIYENTLARI VA NORMASI

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Annotatsiya

Biz ushbu ishda ikkinchi tartibli oddiy differensial tenglamaga qo‘yilgan Koshi masalasini Sobolev fazosi $L_2^{(6)}(0,1)$ da taqribiy hisoblash uchun optimal oshkormas ayirmali formula quramiz va uni yuqoridan bahosini beramiz.

Kalit so‘zlar: Sobolev fazosi, optimal ayirmali formula, ekstremal funksiya, optimal koeffitsiyentlar, oshkormas formula.

Ushbu ishda biz quyidagi ikkinchi tartibli oddiy differensial tenglamani

$$u''(x) = f(x, u(x)), \quad x \in [0, 1], \quad u(x_0) = u_0, \quad u'(x_0) = u_1, \quad (1)$$

boshlang‘ich shartlarga ko‘ra taqribiy yechimini topishni qaraymiz.

Masala (1) ni taqribiy yechish uchun quyidagi umumiy ayirmali formulani qaraymiz [1, 2]:

$$\sum_{\beta=0}^k C[\beta] \phi[\beta] - h^2 \sum_{\beta=0}^k C^{(II)}[\beta] \phi''[\beta] \cong 0 \quad (2)$$

Bu yerda $C[\beta]$ va $C^{(II)}[\beta]$ ayirmali formulaning noma‘lum koeffitsiyentlari, $h = \frac{1}{N}$, $[\beta] = h\beta$, $(\beta = 0, 1, \dots, k)$, $\phi(x) \in L_2^{(6)}(0,1)$. $L_2^{(6)}(0,1)$ Sobolev fazosi bo‘lib, bu fazo quyidagicha aniqlangan:

$$L_2^{(6)}(0,1) = \{ \phi : [0,1] \rightarrow \mathbb{R}, \phi^{(v)}(x) - \text{abs. uzl}, \phi^{(vi)}(x) \in L_2(0,1) \}.$$

$L_2^{(6)}(0,1)$ fazoda ixtiyoriy ikkita ϕ va ψ funksiyalar uchun skalyar ko‘paytma quyidagicha aniqlangan [3]:

$$\langle \psi, \phi \rangle = \int_0^1 \phi^{(6)}(x) \psi^{(6)}(x) dx. \quad (3)$$

Shuningdek, $L_2^{(6)}(0,1)$ fazoda (3)- skalyar ko‘paytmaga mos funksiya normasi quyidagicha aniqlanadi:

$$\| \phi \|_{L_2^{(6)}(0,1)} = \left(\int_0^1 (\phi^{(6)}(x))^2 dx \right)^{\frac{1}{2}}. \quad (4)$$

Qaralayotgan (2)- formulada berilgan yig‘indilar orasidagi

$$\begin{aligned} (\ell, \phi) &= \sum_{\beta=0}^k C[\beta] \phi[\beta] - h^2 \sum_{\beta=0}^k C^{(II)}[\beta] \phi''[\beta] = \\ &= \int_{-\infty}^{\infty} \left[\sum_{\beta=0}^k C[\beta] \delta(x - h\beta) - h^2 \sum_{\beta=0}^k C^{(II)}[\beta] \delta''(x - h\beta) \right] \phi(x) dx. \end{aligned} \quad (5)$$

ayirmaga (2)- ayirmali formulaning xatoligi deyiladi.

Hosil qilingan (5)- ifoda uchun $L_2^{(6)*}(0,1)$ qo‘shma fazoga tegishli quyidagi *xatolik funksionali* mos keladi va uning ko‘rinishi quyidagicha bo‘ladi

$$\ell(x) = \sum_{\beta=0}^k C[\beta] \delta(x-h\beta) - h^2 \sum_{\beta=0}^k C^{(II)}[\beta] \delta''(x-h\beta) \quad , \quad (6)$$

bu yerda $L_2^{(6)*}(0,1)$ fazo bu $L_2^{(6)}(0,1)$ fazoga qo'shma fazo, $\delta(x)$ - Dirakning delta-funksiyasi.

Chiziqli uzluksiz funksionalning normasi haqidagi ta'rifga ko'ra quyidagi ma'lum

$$\|\ell\|_{L_2^{(6)*}} = \sup_{\varphi \neq 0} \frac{|(\ell, \varphi)|}{\|\varphi\|}$$

Oxirgi tenglikdan quyidagi Koshi-Shvars tengsizligi kelib chiqadi

$$|(\ell, \varphi)| \leq \|\ell\|_{L_2^{(6)*}} \cdot \|\varphi\|_{L_2^{(6)}}.$$

Demak, (2)- ayirmali formulaning (5)- xatoligi $L_2^{(6)*}(0,1)$ qo'shma fazodan olingan (6)- xatolik funksionali va $L_2^{(6)}(0,1)$ fazosidan olingan φ funksiyalar normalari orqali yuqoridan baholanadi.

$\varphi(x)$ funksiyaning (4)- normasiga ko'ra quyidagi shartlar o'rinli

$$(\ell, x^\alpha) = 0, \quad \alpha = 0, 1, 2, 3, 4, 5.$$

Demak, xatolik funksionalining normasi $C[\beta]$ va $C^{(II)}[\beta]$ koeffitsiyentlarga hamda $h\beta$ ($\beta = 0, 1, \dots, N$) tugun nuqtalarga bog'liq. Biz qarayotgan optimal ayirmali formulada xatolik funksionalining normasi $C^{(II)}[\beta]$ koeffitsiyentlar bo'yicha minimallashtiriladi. $C[\beta]$

koeffitsiyentlar esa Dalquist ma'nosida $\sum_{\beta=0}^k C[\beta] = 0$ turg'unlik shartini bajaradigan qilib tanlab olinadi.

Ayirmali formula (2) ga ko'ra $k = 3$ da quyidagi teorema o'rinli

Teorema. Sobolevning $L_2^{(6)}(0,1)$ fazosida quyidagi oshkormas ayirmali formula optimal bo'ladi

$$y_{n+2} - 2y_{n+1} + y_n = \frac{h^2}{12} (y_{n+2}'' + 10y_{n+1}'' + y_n''), \quad n = 1, 2, \dots, N-2.$$

Uning xatolik funksionali normasining kvadrati uchun quyidagi tenglik o'rinli:

$$\|\ell\|_{L_2^{(6)*}}^2 = \frac{61}{3742200} h^{11}.$$

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IKKI O'LCHOVLI SIMMETRIK GIPERBOLIK SISTEMALAR UCHUN RUSANOV SXEMASINING DINAMIK CHEGARAVIY SHARTLAR OSTIDA EKSPONENSIAL TURG'UNLIGI

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Annotatsiya

Mazkur ishda ikki o'lchovli chiziqli simmetrik giperbolik sistemalar uchun dinamik chegaraviy shartlar ostida Rusanov (lokal Lax-Fridriks) ayirmali sxemasining turg'unligi tadqiq etilgan. Chegaradagi jarayonlar oddiy differensial tenglamalar orqali modellashtrilib, ichki yechim bilan o'zaro bog'langan. Diskret Lyapunov funksiyasi qurilib, sonli energiyaning eksponensial

kamayishi uchun yetarli shartlar keltirib chiqarilgan. Olingan nazariy natijalar sonli tajribalar yordamida tasdiqlangan.

Kirish

Giperbolik tipdagi differensial tenglamalar fizik va muhandislik masalalarida keng qo'llaniladi. Xususan, to'liq tarqalishi, suyuqliklar harakati, transport jarayonlari kabi ko'plab muammolar aynan shu turdagi tenglamalar orqali ifodalanadi. Bunday masalalarda chegaraviy shartlarning to'g'ri qo'yilishi va ularning tizimga ta'siri alohida ahamiyat kasb etadi.

So'nggi yillarda dinamik chegaraviy shartlar, ya'ni chegaradagi holat oddiy differensial tenglamalar orqali ifodalanuvchi modellar keng o'rganilmoqda. Bunday yondashuv real jarayonlarni yanada aniqroq tasvirlash imkonini beradi, chunki chegarada energiya almashinuvi va dissipatsiya hodisalari yuz beradi.

Shu bilan birga, giperbolik sistemalar uchun ayirmali sxemalar qurishda ularning turg'unligi asosiy masalalardan biri hisoblanadi.

Masalaning qo'yilishi

Ko'rilayotgan soha $\Omega = (0,1) \times (0,1)$ bo'lib, unda quyidagi ikki o'lchovli chiziqli simmetrik giperbolik sistema qaraladi:

$$\frac{\partial u}{\partial t} + A \frac{\partial u}{\partial x} + B \frac{\partial u}{\partial y} = 0:$$

Chegarada dinamik shart:

$$\frac{dw}{dt} + \alpha w = \beta u.$$

Bu yerda $\alpha > 0$ dissipatsiya koeffitsiyenti bo'lib, tizim energiyasining kamayishini ta'minlaydi.

Ayirmali sxema

Masalani yechish uchun ikki o'lchovli Rusanov sxemasi qo'llaniladi. Ushbu sxema konservativ bo'lib, panjara asosida quriladi va oqimlar maxsus formulalar orqali aniqlanadi. Sxemada sonli dissipatsiya mavjud bo'lib, u turg'unlikni ta'minlaydi.

Chegaraviy qiymatlar esa dinamik tenglama yordamida aniqlanadi.

Turg'unlik tahlili

Turg'unlikni isbotlash uchun diskret Lyapunov funksiyasi kiritiladi. Ichki energiya va chegaraviy energiya birgalikda qaraladi. Tahlil davomida Young tengsizligi va diskret iz tengsizligi qo'llaniladi.

Asosiy natija:

$$V^{n+1} - V^n \leq -\kappa \Delta t V^n.$$

Bu sxemaning eksponensial turg'unligini anglatadi.

Sonli tajribalar

Hisoblash natijalari energiyaning eksponensial kamayishini ko'rsatdi. Logarifmik grafiklar chiziqli bo'lib, yechimda tebranishlar kuzatilmadi. Rusanov sxemasi boshqa sxemalarga nisbatan barqarorroq natija berdi.

Xulosa

Mazkur ishda ikki o'lchovli giperbolik sistemalar uchun Rusanov sxemasining eksponensial turg'unligi isbotlandi. Natijalar kelajakda murakkab tizimlar uchun ham qo'llanilishi mumkin.

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УСТОЙЧИВОСТЬ ПО ЛЯПУНОВУ ПРОТИВОПОТОЧНЫХ СХЕМ ДЛЯ НЕЛИНЕЙНЫХ ДВУМЕРНЫХ ГИПЕРБОЛИЧЕСКИХ СИСТЕМ

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Аннотация. В работе рассматривается проблема устойчивости по Ляпунову численных решений нелинейных двумерных гиперболических систем. Исследуется явная противопоточная схема для смешанной задачи с диссипативными граничными условиями. На основе энергетического метода построена дискретная функция Ляпунова и получена оценка невозрастания дискретной энергии. Показано, что при выполнении условия Куранта–Фридрихса–Леви и наличии численной диссипации схема обладает устойчивостью, а при дополнительных условиях — экспоненциальным затуханием энергии.

Гиперболические системы уравнений играют важную роль при моделировании волновых процессов, течений жидкости, динамики газа и других физических явлений. Для практического решения подобных задач широко применяются численные методы, основанные на противопоточных схемах. Однако при построении численного алгоритма возникает важная проблема обеспечения устойчивости решения. Одним из наиболее эффективных подходов к исследованию устойчивости является метод функций Ляпунова.

Рассмотрим нелинейную двумерную гиперболическую систему в консервативной форме

$$U_t + F(U)_x + G(U)_y = 0$$

где $U(x, y, t) \in \mathbb{R}^m$ — вектор неизвестных функций, а $F(U)$ и $G(U)$ — нелинейные потоки по пространственным переменным. Предположим, что система является симметризуемой, то есть существует симметризатор $S(U) = S(U)^T > 0$, удовлетворяющий условиям

$$S(U)A(U) = A(U)^T S(U),$$

$$S(U)B(U) = B(U)^T S(U),$$

где $A(U) = F'(U)$, $B(U) = G'(U)$.

Для численного решения задачи используется явная противопоточная схема. Обозначим через $U_{i,j}^n$ приближённое значение решения в ячейке (i, j) в момент времени $t^n = n\Delta t$. Тогда схема записывается в виде

$$U_{i,j}^{n+1} = U_{i,j}^n - \frac{\Delta t}{\Delta x} \left(\hat{F}_{i+\frac{1}{2},j}^n - \hat{F}_{i-\frac{1}{2},j}^n \right) - \frac{\Delta t}{\Delta y} \left(\hat{G}_{i,j+\frac{1}{2}}^n - \hat{G}_{i,j-\frac{1}{2}}^n \right)$$

где $\hat{F}$ и $\hat{G}$ являются численными потоками. В качестве примера можно использовать поток Русанова:

$$\hat{F}(U_L, U_R) = \frac{1}{2} (F(U_L) + F(U_R)) - \frac{\lambda}{2} (U_R - U_L)$$

Данный поток содержит искусственную вязкость, обеспечивающую численную диссипацию и подавление неустойчивых осцилляций.

Для исследования устойчивости вводится дискретная функция Ляпунова

$$V^n = \sum_{i,j} \Delta x \Delta y (U_{i,j}^n - \bar{U})^T S(U_{i,j}^n - \bar{U})$$

где $\bar{U}$ — стационарное состояние системы. Благодаря положительной определённости матрицы (S) дискретная энергия эквивалентна квадрату нормы решения:

$$c_1 \|U^n - \bar{U}\|^2 \leq V^n \leq c_2 \|U^n - \bar{U}\|^2$$

Далее исследуется изменение энергии на одном временном шаге. После подстановки численной схемы в выражение для $V^{n+1} - V^n$ и применения дискретного аналога интегрирования по частям получаем энергетическое соотношение

$$V^{n+1} - V^n = -D^n - B^n$$

где D^n характеризует внутреннюю численную диссипацию, а B^n — вклад граничных условий.

Для монотонных потоков типа Русанова величина D^n принимает вид

$$D^n = \frac{\lambda}{2} \sum_{i,j} (|U_{i+1,j}^n - U_{i,j}^n|^2 + |U_{i,j+1}^n - U_{i,j}^n|^2)$$

Следовательно,

$$D^n \geq 0$$

При диссипативных граничных условиях также выполняется неравенство

$$B^n \geq 0$$

Таким образом,

$$V^{n+1} \leq V^n$$

то есть дискретная энергия не возрастает со временем. Это означает устойчивость схемы по Ляпунову.

Для корректности полученных оценок необходимо выполнение условия Куранта–Фридрихса–Леви:

$$\frac{\Delta t}{\Delta x} \max |\lambda_x| + \frac{\Delta t}{\Delta y} \max |\lambda_y| \leq C_{\text{КФЛ}}$$

где λ_x и λ_y — максимальные скорости распространения характеристик системы.

В нелинейном случае симметризатор может зависеть от решения. Тогда появляются дополнительные остаточные члены, связанные с вариацией $S(U)$. Однако при малости возмущений и выполнении КФЛ-условия эти слагаемые могут быть поглощены основным диссипативным членом.

Дополнительно можно получить экспоненциальное затухание энергии. Если существует постоянная $\alpha > 0$, такая что

$$D^n \geq \alpha V^n$$

то выполняется оценка

$$V^{n+1} \leq (1 - \alpha) V^n$$

Отсюда следует

$$V^n \leq e^{-\alpha n \Delta t} V^0$$

Данное свойство означает асимптотическую устойчивость численного решения.

Полученные результаты показывают, что противопоточные схемы с монотонными потоками и диссипативными граничными условиями обладают хорошими устойчивостными свойствами при решении нелинейных гиперболических систем. Метод дискретных функций Ляпунова позволяет не только установить устойчивость схемы, но и оценить скорость затухания энергии. Эти результаты могут быть использованы при моделировании задач гидродинамики, уравнений Сен-Венана, газовой динамики и других прикладных задач математической физики.

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OPTIMAL APPROXIMATE ANALYTICAL SOLUTION OF THE CHARACTERISTIC SINGULAR INTEGRAL EQUATION WITH THE HILBERT KERNEL

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Introduction. Singular integral equations with a Hilbert kernel arise in the process of mathematical representation of many problems in physics and mechanics [1]. One such integral equation is a characteristic singular integral equation with a Hilbert kernel of the Fredholm type of the second kind

$$a \cdot g(t) + \frac{b}{2\pi} \int_0^{2\pi} g(x) \cot \frac{x-t}{2} dx = \varphi(t), \quad (1)$$

where a and b are constants, and $\varphi(t)$ and $g(t)$ are functions with a period of 2π .

The kernel

$$\cot \frac{x-t}{2}$$

is called a Hilbert kernel and is considered in the sense of the principal value that has a specificity when $0 \leq x \leq 2\pi$, $0 < t < 2\pi$ in the square $x = t$.

Using Hilbert transformations, the solution of integral equation (1) is expressed as follows [2]

$$g(t) = \frac{a}{a^2 + b^2} \varphi(t) - \frac{b}{2\pi(a^2 + b^2)} \int_0^{2\pi} \varphi(x) \cot \frac{x-t}{2} dx + \frac{b^2}{2\pi a(a^2 + b^2)} \int_0^{2\pi} \varphi(x) dx \quad (2)$$

If and only if $a = 0$ in equation (1)

$$\int_0^{2\pi} \varphi(x) dx = 0$$

satisfying the condition, has the following solution

$$g(t) = -\frac{b}{2\pi} \int_0^{2\pi} \varphi(x) \cot \frac{x-t}{2} dx + C, \quad C \in \mathbb{C}. \quad (3)$$

If $a^2 + b^2 = 0$, then equation (1) has no solution.

The main problem encountered in solutions (2) and (3) of the integral equation (1) is the calculation of the singular integral

$$\int_0^{2\pi} \varphi(x) \cot \frac{x-t}{2} dx \quad (4)$$

which is considered in the sense of the principal value. This problem persists even with different transformations of solutions (2) and (3).

Our goal in this work is to develop a more efficient and general numerical solution algorithm for the aforementioned methods. To do this, using the functional method, we construct an optimal quadrature formula for the approximate calculation of the singular integral with a Hilbert kernel (4).

For this method, functions belonging to the space $L_2^{(m)}(0, 2\pi)$ are considered, and this space is defined as follows:

$$L_2^{(m)}(0, 2\pi) = \{\varphi(x) : [0, 2\pi] \rightarrow \mathbb{R}, \varphi^{(m-1)}(x) - \text{abs. cont. and } \varphi^{(m)}(x) \in L_2(0, 2\pi)\}.$$

In this space $L_2^{(m)}(0, 2\pi)$, the scalar product of two functions is defined as follows:

$$\langle \varphi, g \rangle = \int_0^{2\pi} \varphi^{(m)}(x) g^{(m)}(x) dx \quad (5)$$

and the norm of the function $\varphi(x)$ in this space is introduced using the scalar product (5) as follows:

$$\|\varphi(x)\| = \sqrt{\langle \varphi, \varphi \rangle} = \sqrt{\int_0^{2\pi} (\varphi^{(m)}(x))^2 dx} \quad (6)$$

$$\text{and } \int_0^{2\pi} (\varphi^{(m)}(x))^2 dx < \infty.$$

Consider the following quadrature formula

$$\int_0^{2\pi} \varphi(x) \cot \frac{x-t}{2} dx \cong \sum_{\beta=0}^N C_\beta \varphi(x_\beta) \quad (7)$$

and this formula corresponds to the following error functional

$$\ell(x) = \varepsilon_{[0, 2\pi]}(x) \cot \frac{x-t}{2} - \sum_{\beta=0}^N C_\beta \delta(x - x_\beta), \quad (8)$$

where $\varphi(x) \in L_2^{(m)}(0, 2\pi)$, C_β are the coefficients and x_β are the nodes of the quadrature formula (7), $N \in \mathbb{N}$. $\varepsilon_{[0, 2\pi]}(x)$ is the characteristic functions of the interval $[0, 2\pi]$, and $\delta(x)$ is the Dirac delta-function.

In the quadrature formula (7) under consideration, the relationship between the integral and the quadrature sum

$$\int_0^{2\pi} \varphi(x) \cot \frac{x-t}{2} dx - \sum_{\beta=0}^N C_\beta \varphi(x_\beta) = \int_{-\infty}^{\infty} \ell(x) \varphi(x) dx = (\ell, \varphi) \quad (9)$$

the difference is called the *error of the quadrature formula*.

The error of quadrature formula (7) corresponds to a linear continuous error functional belonging to the space $L_2^{(m)*}(0, 2\pi)$, where $L_2^{(m)*}(0, 2\pi)$ is a space conjugate to this space $L_2^{(m)}(0, 2\pi)$.

According to the definition of the norm of a linear continuous functional, the following is known [3]:

$$\|\ell\|_{L_2^{(m)*}} = \sup_{\|\varphi\| \neq 0} \frac{|(\ell, \varphi)|}{\|\varphi\|}.$$

From the last equality, we have the following Cauchy-Schwartz inequality:

$$|(\ell, \varphi)| \leq \|\ell\|_{L_2^{(m)*}} \cdot \|\varphi\|_{L_2^{(m)}}.$$

From the Cauchy-Schwartz inequality, it can be seen that the following conditions hold for the function $\varphi(x)$ according to norm (6)

$$(\ell, x^\alpha) = 0, \quad \alpha = 0, 1, 2, \dots, m-1. \quad (10)$$

Problem 1. Find the form of the norm of the error functional $\ell(x)$ of quadrature formula (7) with respect to C_β and x_β .

As we can see, the norm of the error functional $\ell(x)$ depends on the coefficients C_β and the nodal points x_β . We can minimize the norm of the error functional $\ell(x)$ with respect to these coefficients C_β and nodal points x_β . The problem of minimizing the quantity $\|\ell\|$ with respect to the coefficients C_β is linear, whereas the problem of minimizing it with respect to both the coefficients C_β and the nodal points x_β is a more complex nonlinear problem. In this work, we consider the problem of minimizing the norm of the error functional $\ell(x)$ only with respect to the coefficients C_β at equally distributed nodal points $x_\beta = h\beta$, where $h = \frac{2\pi}{N}$, $\beta = 0, 1, \dots, N$, $N \in \mathbb{N}$.

This problem is called the Sard problem because Sard first considered it in his works.

If there are coefficients C_β minimizing the norm of the error functional $\ell(x)$, i.e.

$$\inf_{C_\beta} \|\ell\| \quad (11)$$

are called *optimal coefficients* and are denoted by $\hat{C}_\beta$. The quadrature formula (7) constructed using these optimal coefficients is called the optimal quadrature formula.

Now we will deal with solving these issues sequentially. Extreme function and the norm of the error functional. First, let us solve problem 1, i.e., find the form of the norm of the error functional $\ell(x)$ in the space $L_2^{(m)*}(0, 2\pi)$. To do this, we will use the definition of an extremal function.

Definition. The function $\psi_\ell(x)$ corresponding to the error functional $\ell(x)$, which converts the Cauchy-Schwarz inequality to equality, is called an extreme function:

$$(\ell, \psi_\ell) = \|\ell\| \|\psi_\ell\|$$

and its appearance is defined as follows

$$\psi_\ell(x) = (-1)^m \ell(x) * G_m(x) + P_{m-1}(x),$$

where $G_m(x) = \frac{|x|^{2m-1}}{2(2m-1)!}$, $P_{m-1}(x)$ is a polynomial of degree $m-1$, and $*$ is the convolution operation.

Here, the extremal function $\psi_\ell(x)$ is a Riesz element, and the following equality holds:

$$(\ell, \psi_\ell) = \|\ell\|^2 = \|\psi_\ell\|^2.$$

Based on the last expression, we calculate the square of the norm of the error functional

$$\begin{aligned} \|\ell\|^2 &= (\ell, \psi_\ell) = \int_{-\infty}^{\infty} \ell(x) \psi_\ell(x) dx = \\ &= \int_{-\infty}^{\infty} \left(\varepsilon_{[0,1]}(x) \cot \frac{x-t}{2} - \sum_{\beta=0}^N C_\beta \delta(x-h\beta) \right) ((-1)^m \ell(x) * G_m(x) + P_{m-1}(x)) dx. \end{aligned}$$

From this, we have the following:

$$\begin{aligned} \|\ell\|^2 &= (-1)^m \left(\sum_{\beta=0}^N \sum_{\gamma=0}^N C_\beta C_\gamma \frac{|h\beta - h\gamma|^{2m-1}}{2(2m-1)!} - 2 \sum_{\beta=0}^N C_\beta \int_0^{2\pi} \frac{|x - h\beta|^{2m-1}}{2(2m-1)!} \cot \frac{x-t}{2} dx + \right. \\ &\quad \left. + \int_0^{2\pi} \int_0^{2\pi} \frac{|x-y|^{2m-1}}{2(2m-1)!} \cot \frac{x-t}{2} \cot \frac{y-t}{2} dx dy \right) \quad (12) \end{aligned}$$

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$W_2^{(7,6)}(0,1)$ FAZOSIDA OPTIMAL KVADRATUR FORMULA QURISH

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Annotatsiya: Ushbu ishda $W_2^{(7,6)}(0,1)$ Gilbert fazosida Sobolev usuli yordamida Sard ma'nosidagi kvadratur formula qurilgan va uning optimal koeffisientlari topilgan.

Masalaning qo'yilishi. Biz quyidagi kvadratur formulani qaraymiz:

$$\int_0^1 \varphi(x) dx \cong \sum_{\beta=0}^N C_0[\beta] \varphi(h\beta) + \sum_{\beta=0}^N C_1[\beta] \varphi'(h\beta) + \sum_{\beta=0}^N C_3[\beta] \varphi'''(h\beta) + \sum_{\beta=0}^N C_5[\beta] \varphi^{(5)}(h\beta) + \sum_{\beta=0}^N C_6[\beta] \varphi^{(6)}(h\beta) \quad (1)$$

bunda C_0, C_1, C_3, C_5 -ma'lum koeffisientlar, ya'ni

$$C_0[\beta] = \begin{cases} h/2, \beta = 0 \\ h, \beta = \overline{1, N-1} \\ h/2, \beta = N \end{cases} \quad C_1[\beta] = \begin{cases} h^2/12, \beta = 0 \\ 0, \beta = \overline{1, N-1} \\ -h^2/12, \beta = N \end{cases}$$

$$C_3[\beta] = \begin{cases} -h^4/720, \beta = 0 \\ 0, \beta = \overline{1, N-1} \\ h^4/720, \beta = N \end{cases} \quad C_5[\beta] = \begin{cases} h^6/30240, \beta = 0 \\ 0, \beta = \overline{1, N-1} \\ -h^6/30240, \beta = N \end{cases}$$

$C_6[\beta]$ - (1) kvadratur formulani hozircha noma'lum koeffisientlari, $h = \frac{1}{N}$, N - natural son.

Bu yerda integral ostidagi φ funksiyalar $W_2^{(7,6)*}(0,1)$ fazoga tegishli. Bunda $W_2^{(7,6)}(0,1)$ fazo sifatida oltinchi tartibli hosilasi absolyut uzluksiz yettinchi tartibli hosilasi $L_2(0,1)$ fazosiga tegishli funksiyalar sinfini olamiz. Bu $W_2^{(7,6)*}(0,1)$ sinfida skalyar ko'paytma quyidagicha kiritilgan:

$$\langle \varphi, \psi \rangle = \int_0^1 (\varphi^{(7)}(x) + \varphi^{(6)}(x)) * (\psi^{(7)}(x) + \psi^{(6)}(x)) dx \quad (2)$$

yarim skalyar ko'paytmaga nisbatan Gilbert fazosi bo'ladi. Bu skalyar ko'paytma yordamida quyidagi normani qaraymiz:

$$\|\varphi\|_{W_2^{(7,6)}} = \left(\int_0^1 (\varphi^{(7)}(x) + \varphi^{(6)}(x)) dx \right)^{1/2} \quad (3)$$

(1) kvadratur formulaning xatoligi deb

$$\int_0^1 \varphi(x) dx - \left(\sum_{\beta=0}^N C_0[\beta] \varphi(h\beta) + \sum_{\beta=0}^N C_1[\beta] \varphi'(h\beta) + \sum_{\beta=0}^N C_3[\beta] \varphi'''(h\beta) + \sum_{\beta=0}^N C_5[\beta] \varphi^{(5)}(h\beta) + \sum_{\beta=0}^N C_6[\beta] \varphi^{(6)}(h\beta) \right) \quad (4)$$

ayirmaga aytiladi. Bu ayirmaga $W_2^{(7,6)}(0,1)$ fazosida aniqlangan quyidagi funksional mos keladi:

$$\ell(x) = \varepsilon_{[0,1]}(x) - \sum_{\beta=0}^N C_0[\beta] \delta(x-h\beta) - \sum_{\beta=0}^N C_1[\beta] \delta'(x-h\beta) -$$

$$-\sum_{\beta=0}^N C_3[\beta] \delta^{(3)}(x-h\beta) - \sum_{\beta=0}^N C_5[\beta] \delta^{(5)}(x-h\beta) - \sum_{\beta=0}^N C_6[\beta] \delta^{(6)}(x-h\beta) \quad (5)$$

bunda $\varepsilon_{[0,1]}(x)$ - $[0,1]$ kesmaning xarakteristik funksiyasi, $\delta(x)$ - Dirakning delta-funksiyasi.

(1) kvadratur formulaning ℓ xatolik funksionali $W_2^{(7,6)*}(0,1)$ qo'shma fazoga tegishli chiziqli funksionaldir. Shu bilan birga, (5) xatolik funksionali $W_2^{(7,6)}(0,1)$ fazoda aniqlanganligi uchun quyidagi tengliklarni qanoatlantirishi shartdir:

$$(\ell, 1) = 1 - \sum_{\beta=0}^N C_0[\beta] = 0, \quad (7)$$

$$(\ell, x) = \frac{1}{2} - \sum_{\beta=0}^N C_0[\beta] \varphi(h\beta) = 0, \quad (8)$$

$$(\ell, x^2) = \frac{1}{3} - \sum_{\beta=0}^N C_0[\beta] \varphi(h\beta)^2 - 2 \sum_{\beta=0}^N C_1[\beta] (h\beta) = 0, \quad (9)$$

$$(\ell, x^3) = \frac{1}{4} - \sum_{\beta=0}^N C_0[\beta] \varphi(h\beta)^3 - 3 \sum_{\beta=0}^N C_1[\beta] (h\beta)^2 - 6 \sum_{\beta=0}^N C_3[\beta] = 0, \quad (10)$$

$$(\ell, x^4) = \frac{1}{5} - \sum_{\beta=0}^N C_0[\beta] \varphi(h\beta)^4 - 4 \sum_{\beta=0}^N C_1[\beta] (h\beta)^3 - 24 \sum_{\beta=0}^N C_3[\beta] (h\beta) = 0, \quad (11)$$

$$(\ell, x^5) = \frac{1}{6} - \sum_{\beta=0}^N C_0[\beta] \varphi(h\beta)^5 - 5 \sum_{\beta=0}^N C_1[\beta] (h\beta)^4 - \\ - 60 \sum_{\beta=0}^N C_3[\beta] (h\beta)^2 + 120 C_5[\beta] = 0 \quad (12)$$

$$(\ell, e^{-x}) = 1 - e^{-1} - \sum_{\beta=0}^N C_0[\beta] \cdot e^{-(h\beta)} + \sum_{\beta=0}^N C_1[\beta] \cdot e^{-(h\beta)} + \\ + \sum_{\beta=0}^N C_3[\beta] \cdot e^{-(h\beta)} + \sum_{\beta=0}^N C_5[\beta] \cdot e^{-(h\beta)} + \sum_{\beta=0}^N C_6[\beta] \cdot e^{-(h\beta)} \quad (13)$$

Yuqoridagi (7)-(12) tengliklardan (1) kvadratur formulaning beshinchi tartibli ko'phadga aniqligini bildiradi. Biz $C_6[\beta]$ koefitsientlarni (7)-(12) shartlarni bajariladigan qilib tanlab oldik. Hozirgi noma'lum bo'lgan $C_6[\beta]$, $\beta=0,1,\dots,N$ koefitsientlar (13) tenglikni qanoatlantiradigan qilib topishimiz kerak. Demak biz $C_6[\beta]$ koefitsientlar uchun faqatgina (13)-shartga ega bo'lamiz.

(1) kvadratur formulaning (6) xatoligi $W_2^{(7,6)*}(0,1)$ fazosidan chiziqli funksional bo'ladi, bunda $W_2^{(7,6)*}$ -bu $W_2^{(7,6)}$ fazosiga qo'shma fazo. U holda Koshi-Shvars tengsizligidan (6) xatolikning absolyut qiymati yuqoridan quyidagicha baholanadi:

$$|(\ell, \varphi)| \leq \|\varphi\|_{W_2^{(7,6)}(0,1)} \cdot \|\ell\|_{W_2^{(7,6)*}(0,1)}.$$

Bu yerdan biz (1) kvadratur formulaning (6) xatoligi $\ell(x)$ xatolik funksionalining

$$\|\ell\|_{W_2^{(7,6)*}(0,1)} = \sup_{\varphi, \|\varphi\| \neq 0} \frac{|(\ell, \varphi)|}{\|\varphi\|_{W_2^{(7,6)}(0,1)}}$$

normasi orqali baholanishini xulosa qilamiz. Bu yerda $\ell(x)$ xatolik funksionalining normasi $C_6[\beta]$, $\beta=0, \overline{N}$ koefitsientlarga bog'liqligini ko'rish qiyin emas. Tabiiyki, butun bir funksiyalar fazosi $W_2^{(7,6)}(0,1)$ elementlarida (1) kvadratur formula xatoligini yuqori chegarasining eng kichik qiymatini topish muhim hisoblanadi. Xatolik funksionali normasi $C_6[\beta]$ koefitsientlarga bo'yicha minimumini topish masalasi Sard masalasi bo'ladi.

Bu masalani yechish natijasida olingan kvadratur formula Sard manosida optimal kvadratur formula deyiladi.

Ushbu ishning asosiy maqsadi $W_2^{(7,6)}(0,1)$ fazosida (1) kvadratur formula uchun Sard masalasi yechishdan iboratdir, ya'ni

$$\|\dot{\ell}\| = \inf_{C_6[\beta]} \|\ell\| \quad (14)$$

tenglikni qanoatlantiruvchi $C_6[\beta]$ koeffisientlarni topishdan iboratdir.

Shunday qilib, $W_2^{(6,5)}(0,1)$ fazosida (1) ko'rinishidagi Sard manosida optimal kvadratur formulani qurish uchun quyidagi ikkita masalani ketma-ket yechishimiz kerak.

1 – masala. (1) kvadratur formulaning (5) xatolik funksionali normasi hisoblash.

2 – masala. (14) tenglikni qanoatlantiruvchi $C_6[\beta]$ koeffisientlar topish.

Yuqoridagi masalalarni yechish natijasida quyidagi asosiy teoremani olamiz.

Teorema. $W_2^{(7,6)}(0,1)$ fazosida (1) ko'rinishidagi kvadratur formulaning optimal koeffisientlari quyidagi ko'rinishga ega

$$\begin{aligned} \overset{\circ}{C}_6[0] &= \frac{e^h - 1}{e^h + 1} \left(1 + \frac{h^2}{12} - \frac{h^4}{720} + \frac{h^6}{30240} \right) - \frac{h}{2}, \\ \overset{\circ}{C}_6[\beta] &= \frac{e^h - 1}{e^h + 1} \left(2 + \frac{h^2}{6} - \frac{h^4}{360} + \frac{h^6}{15120} \right) - h, \\ \overset{\circ}{C}_6[N] &= \frac{e^h - 1}{e^h + 1} \left(1 + \frac{h^2}{12} - \frac{h^4}{720} + \frac{h^6}{30240} \right) - \frac{h}{2}. \end{aligned}$$

Foydalanilgan adabiyotlar

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КУМУЛЯТИВНЫЕ ОЦЕНКИ МАТЕМАТИЧЕСКОГО ОЖИДАНИЯ ДИСКРЕТНОЙ СЛУЧАЙНОЙ ВЕЛИЧИНЫ И ИХ ИСПОЛЬЗОВАНИЕ В АНАЛИЗЕ НАДЁЖНОСТИ СЕТЕЙ

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Аннотация. В докладе рассматриваются кумулятивные оценки математического ожидания дискретной случайной величины, получаемые на основе выборки без возвращения, и основанные на них точечные оценки. Рассматривается использование этих оценок применительно к анализу надёжности сетей, представленных в виде неориентированного случайного графа с надёжными вершинами и независимо отказывающимися рёбрами.

Кумулятивные оценки

Идея использования кумулятивных оценок надёжности сети, оцениваемой как вероятность связности всех вершин случайного графа (All Terminal Reliability, ATR) для однозначного решения относительно заданного порога, была представлена в работе [1]. В [2] были предложены некоторые улучшения алгоритма. Дадим описание кумулятивных оценок.

Математическое ожидание дискретной случайной величины получается по известной формуле $E[X] = \sum_{i=1}^N p_i x_i$.

Представим, что получена выборка без возвращения объёма $k < N$. Тогда, если известны возможные минимальное (m_x) и максимальное (M_x) значения случайной величины, то получаем её *кумулятивные* границы, сходящиеся к точному значению при $k=N$:

$$LB_k = \sum_{i=1}^k x_i p_i + m_x \left(1 - \sum_{i=1}^k p_i\right) \leq E[X] \leq \sum_{i=1}^k x_i p_i + M_x \left(1 - \sum_{i=1}^k p_i\right) = UB_k,$$

Пересечение одной из границ заданного порогового уровня позволяет принимать однозначное решение без возможности ошибок первого или второго рода.

Пусть требуется получить точечную оценку математического ожидания на основе кумулятивных границ. Наиболее очевидным решением является использовать их среднее арифметическое $\bar{X}_k = (LB_k + UB_k)/2$, но границы могут меняться с разными скоростями, с тем большей разницей, чем истинное значение математического ожидания отличается от $(m_x + M_x)/2$. В [3] исследуется оценка, названная нами *оценкой по тренду*. Эта оценка определяется точкой пересечения прямых, проходящих через точки $(1, m_x)$ и (k, LB_k) , и $(1, M_x)$ и (k, UB_k) , соответственно. Её значение легко получается как

$$\tilde{X}_k = \frac{M_x \cdot LB_k - m_x \cdot UB_k}{M_x - UB_k - m_x + LB_k}.$$

Можно показать, что оценка $\bar{X}_k$ асимптотически несмещена, тогда как оценка $\tilde{X}_k$ является несмещённой. При этом дисперсия второй оценки превышает дисперсию первой.

Применение кумулятивных границ в анализе случайных графов

Для случая неориентированного случайного графа G с надёжными вершинами и независимо отказывающимися рёбрами вероятность его конкретной реализации H легко получить как

$$P(H) = \prod_{e \in H} p_e \prod_{e \in G \setminus H} (1 - p_e),$$

где p_e – вероятность присутствия (надёжность) ребра e в графе.

Чтобы обеспечить выборку реализаций графа без возвращения, удобно перенумеровать реализации используя в качестве двоичного представления номера реализации её маску, получаемую с помощью нумерации рёбер (все элементы маски равны единице при присутствии всех рёбер и нулю при их полном отсутствии). Количество реализаций растёт с ростом количества рёбер как 2^m , где m – количество рёбер графа, что определяет NP-трудность получения точных значений показателей [4].

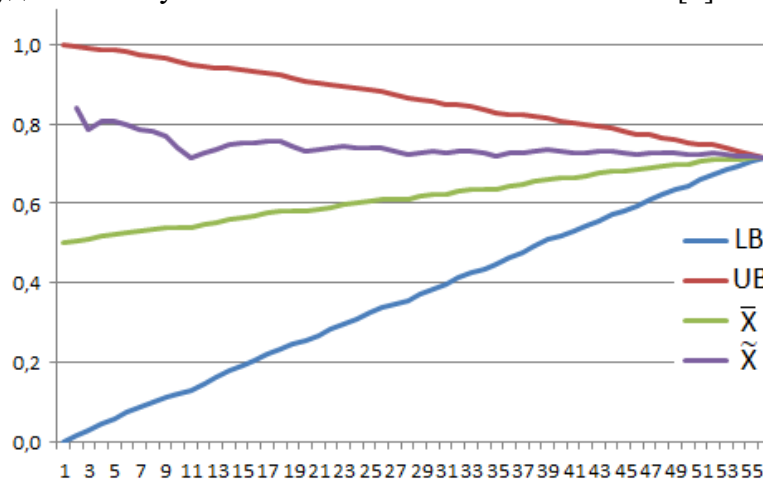


Рисунок 1. Поведение кумулятивных границ и основанных на них точечных оценок

Различные показатели надёжности сети, моделируемой случайным графом, например, вероятность связности заданного подмножества вершин, вероятность установления произвольного парного соединения, математическое ожидание максимального потока, ожидаемый размер связного подграфа, содержащего выделенную (центральную) вершину и др., дают различные значения возможных минимальных и максимальных значений. При этом в ходе эксперимента, о мере удаления из выборочного пространства учтённых реализаций, эти значения могут меняться. Учёт этого показателя может улучшить сходимость границ и,

соответственно, точность точечных оценок. Стоит отметить также возможность получать более простые выражения для случая индикаторных функций, когда показатель бинарен (например, связан-несвязен) и можно использовать известные вероятностные распределения.

В докладе также показано, что управление стратегией выбора реализаций может ускорить подтверждение или опровержение гипотез о нахождении математического ожидания показателя относительно заданного порога. Ранее эти вопросы обсуждались в [5].

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KOMPYUTER TOMOGRAFIYASI TASVIRLARINI FURYE ALMASHTIRISHI YORDAMIDA QAYTA ISHLASH

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Annotatsiya. Ushbu maqolada kompyuter tomografiyasi tasvirlariga Furye almashtirish yordamida chastota sohasida ishlov berish usullari tahlil qilindi. Tasvirni sonli matritsa ko'rinishiga o'tkazish, Furye almashtirishni qo'llash hamda low-pass, high-pass va Gauss filtrlar yordamida tasvirni qayta ishlash bosqichlari amaliy jihatdan o'rganildi. Tadqiqot davomida Python dasturlash tili, NumPy va Pillow kutubxonalaridan foydalanildi. Natijalar shuni ko'rsatdiki, low-pass filtr tasvirdagi yuqori chastotali shovqinlarni kamaytirsa, high-pass filtr qirralar va mayda detallarning ajralib chiqishiga xizmat qiladi. Gauss filtr esa chastotalarni silliq kamaytirishi sababli tabiiyroq natija hosil qiladi. Olingan natijalar Furye almashtirishning kompyuter tomografiyasi tasvirlariga raqamli ishlov berishda samarali usul ekanligini ko'rsatdi.

Kalit so'zlar: Furye almashtirish, chastota sohasi, raqamli tasvir, low-pass filtr, high-pass filtr, Gauss filtr, tasvirlarni qayta ishlash, NumPy, Python.

Hozirgi kunda kompyuter tomografiyasi tasvirlariga raqamli ishlov berish masalalari sun'iy intellekt, tibbiy diagnostika va amaliy matematikaning ko'plab yo'nalishlarida muhim o'rin egallaydi. Tasvirlarni qayta ishlashda chastota sohasidagi usullar alohida ahamiyatga ega bo'lib, ular yordamida tasvir tarkibidagi foydali va foydasiz komponentalarni ajratish mumkin. Furye almashtirishi signal va tasvirlarni chastota sohasida ifodalash imkonini beruvchi eng muhim matematik usullardan biridir. Ushbu usul yordamida tasvir tarkibidagi past va yuqori chastotali komponentalarni tahlil qilish, filtrlash hamda tasvir sifatini yaxshilash mumkin.

Kompyuter tomografiyasi (KT) tibbiy diagnostikada inson organizmining ichki tuzilishini yuqori aniqlikda tasvirlash imkonini beradi. Biroq KT tasvirlarida shovqinlar, artefaktlar³ va tasvir sifatining pasayishi kabi muammolar uchraydi.

³ Artifact (medical imaging) – tibbiy tasvirlarda haqiqiy anatomik tuzilishga mos kelmaydigan noto'g'ri tasvir, buzilish yoki qo'shimcha effektlarning paydo bo'lishidir.

Mazkur ishda Furiye almashtirish yordamida KT tasvirlarini qayta ishlash masalasi qaralib, tasvirlarga filtr qo'llash usullari nazariy va amaliy jihatdan tahlil qilinadi.

Faraz qilamiz, tasvir $f(x, y)$ funksiyasi bilan ifodalanadi. Uning ikki o'lchovli Furiye almashtirishi quyidagi integral orqali aniqlanadi:

$$F(u, v) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} f(x, y) e^{-2\pi j(ux+vy)} dx dy$$

bu yerda $f(x, y)$ – dastlabki KT tasviri, $F(u, v)$ – tasvirning chastota spektri, j – mavhum birlik ($j^2 = -1$), u, v – chastota koordinatalari. Tasvirni qayta tiklash uchun

$$f(x, y) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} F(u, v) e^{2\pi j(ux+vy)} dx dy$$

teskari Furiye almashtirishi qo'llaniladi.

Raqamli tasvir piksel qiymatlaridan tashkil topgan ikki o'lchovli matritsa hisoblanadi. Har bir piksel yorug'lik intensivligini ifodalaydi va 0 dan 255 gacha qiymat qabul qiladi.

Kulrang tasvir uchun:

$$I = \{I(x, y) | 0 \leq x < M, 0 \leq y < N\}$$

bu yerda x, y – piksel koordinatalari, $I(x, y)$ – piksel intensivligi, M, N – tasvir o'lchamlari (ustun va qatordagi piksellari soni).

Tasvirni sonli ko'rinishga o'tkazish uchun Python dasturlash tilining Pillow va NumPy kutubxonalaridan foydalanildi.

Ikki o'lchovli diskret Furiye almashtirish quyidagicha aniqlanadi:

$$F(u, v) = \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) e^{-2\pi j \left(\frac{ux}{M} + \frac{vy}{N} \right)}.$$

Diskret Furiye almashtirishi rasmni sinus va kosinus to'lqinlar yig'indisi sifatida ifodalaydi. Furiye almashtirish natijasida tasvir kompleks sonlardan iborat matritsaga aylanadi. Teskari Furiye almashtirish esa:

$$f(u, v) = \frac{1}{MN} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x, y) e^{2\pi j \left(\frac{ux}{M} + \frac{vy}{N} \right)}$$

formula orqali amalga oshiriladi.

Filtrlash usullari

1. Low-pass filtr. Low-pass filtr past chastotalarni saqlab qoladi va yuqori chastotali komponentalarni kamaytiradi. Natijada tasvir silliqlashadi va mayda shovqinlar kamayadi.

Low-pass filtr:

$$H(u, v) = \begin{cases} 1, & \text{agar } D(u, v) \leq D_0 \\ 0, & \text{agar } D(u, v) > D_0 \end{cases}$$

bu yerda $D(u, v)$ – markazdan masofa, D_0 – kesish radiusi.

Amaliy natijada tasvirning umumiy strukturasi saqlanib, mayda detallar xiralashgani kuzatildi.

2. High-pass filtr. High-pass filtr yuqori chastotalarni ajratib olish uchun qo'llaniladi. Ushbu filtr qirralar va mayda detallarning ajralib chiqishiga xizmat qiladi.

Filtr formulasi:

$$H(u, v) = \begin{cases} 0, & \text{agar } D(u, v) \leq D_0 \\ 1, & \text{agar } D(u, v) > D_0 \end{cases}$$

Natijada tasvirning konturlari va qirralari aniqroq ko'rinishga ega bo'ldi.

3. Gauss filtri. Gauss filtri chastotalarni silliq kamaytirish asosida ishlaydi va ringing effektini kamaytiradi. Gauss filtrlash formulasi:

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

bu yerda σ – filtrlash parametri.

Asl tasvir



Gauss filtrlangan tasvir



1-rasm. Tasvirni filtrlash natijasi

Gauss filtrlangan tasvir: Tasodifiy shovqinlar kamaygan, lekin konturlar biroq yumshatilgan tasvir. Bu yerda σ qiymatini oshirganimiz sari filtrlangan tasvirning sifati oshishni boshlaydi. Gauss filtr natijasida low-pass filtrga qaraganda tabiiyroq va silliqroq tasvir hosil qilindi.

Tadqiqot davomida Furiye almashtirish asosida bir nechta filtrlar amaliy sinovdan o'tkazildi. Low-pass filtr tasvirdagi yuqori chastotali komponentalarni kamaytirib, tasvirni silliqlovchi. High-pass filtr esa qirralar va mayda detallarni ajratib ko'rsatdi. Gauss filtr yordamida ringing effektlari kamaygani va tasvirning tabiiyligi saqlangani kuzatildi. Furiye almashtirishdan so'ng teskari almashtirish qo'llanganda dastlabki tasvir deyarli to'liq tiklandi. Hisoblangan xatolik qiymatlari juda kichik ekanligi aniqlandi. Olingan natijalar Furiye asosidagi filtrlarning tasvirlarga raqamli ishlov berishda samarali ekanligini ko'rsatdi.

Mazkur ishda Furiye almashtirish yordamida tasvirlarni chastota sohasida qayta ishlash usullari o'rganildi. Tasvirni sonli matritsaga o'tkazish, Furiye almashtirishni qo'llash va teskari almashtirish yordamida dastlabki tasvirni tiklash jarayonlari amalga oshirildi. Low-pass, high-pass va Gauss filtrlar amaliy jihatdan tahlil qilinib, ularning tasvirga ta'siri solishtirildi. Gauss filtrning tasvirni tabiiy silliqlovchidagi samaradorligi aniqlandi. Tadqiqot natijalari Furiye almashtirishning kompyuter tomografiyasi tasvirlariga raqamli ishlov berish masalalarida muhim matematik vosita ekanligini ko'rsatdi.

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ИНТЕГРАЛЬНОЕ УРАВНЕНИЕ АБЕЛЯ В ЗАДАЧАХ ТЕЛЕКОММУНИКАЦИИ

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Аннотация

В данной статье рассматриваются возможности применения интегрального уравнения Абеля в задачах телекоммуникации и обработки сигналов. Исследуются математические основы интегрального уравнения Абеля, методы его решения и

практическое использование при восстановлении сигналов, обработке данных и моделировании процессов передачи информации.

Ключевые слова

Интегральное уравнение Абеля, телекоммуникации, обработка сигналов, интегральные уравнения, восстановление сигнала, математическое моделирование.

Введение

Современные телекоммуникационные системы требуют эффективных методов обработки и восстановления информации. При передаче сигналов по каналам связи возникают различные помехи, искажения и потери данных. Для описания подобных процессов широко применяются интегральные уравнения, позволяющие строить математические модели распространения и преобразования сигналов.

Одним из важных типов интегральных уравнений является уравнение Абеля. Данное уравнение активно используется в задачах математической физики, теории сигналов, радиолокации, оптики и телекоммуникации.

Классическое интегральное уравнение Абеля первого рода имеет вид:

$$\int_0^x \frac{\varphi(t) dt}{(x-t)^\alpha} = f(x),$$

где $0 < \alpha < 1$, называется обобщенным уравнением Абеля.

Если $\alpha = \frac{1}{2}$, тогда решение данного уравнения определяется формулой:

$$\varphi(x) = \frac{1}{\pi} \frac{d}{dx} \int_0^x \frac{f(t)}{\sqrt{x-t}} dt.$$

Эта формула играет важную роль при восстановлении неизвестных сигналов в системах передачи данных.

В телекоммуникационных системах информация передаётся в виде электрических, оптических или радиоволн. Во время передачи сигнал подвергается затуханию, шумовым воздействиям, временным задержкам, интерференции и искажению спектра.

Для математического описания таких процессов используются интегральные модели. В частности, интегральное уравнение Абеля позволяет описывать процессы накопления и преобразования сигналов во времени. Например, сигнал на выходе канала связи может быть представлен как свёртка исходного сигнала и функции отклика канала:

$$y(t) = \int_0^t K(t-\tau)x(\tau)d\tau,$$

где $x(\tau)$ - входной сигнал, $K(t-\tau)$ - характеристика канала, $y(t)$ - выходной сигнал. При выборе специального ядра задача сводится к уравнению Абеля.

Во многих телекоммуникационных системах требуется восстановить исходный сигнал по данным, полученным после прохождения через канал связи. Если канал вызывает интегральное преобразование типа Абеля, задача восстановления сводится к решению обратной задачи.

Задача. Пусть принятый сигнал задаётся выражением:

$$r(t) = \int_0^t \frac{s(\tau)}{\sqrt{t-\tau}} d\tau + n(t),$$

где $s(\tau)$ — исходный сигнал, $n(t)$ — шум, $r(t)$ — наблюдаемый сигнал.

Тогда задача восстановления сигнала заключается в нахождении функции $s(t)$.

Интегральные модели используются при построении алгоритмов фильтрации шумов в цифровой связи. Уравнение Абеля помогает учитывать накопительный эффект шумовых процессов и разрабатывать методы регуляризации.

Основном на практике применяются метод Тихонова, квадратурные методы, оптимальные алгоритмы восстановления.

Уравнение Абеля применяется при реконструкции профиля светового пучка, анализе интенсивности сигнала, обработке лазерных импульсов и диагностике оптоволоконных линий.

Численные методы решения

Для практического применения уравнения Абеля в телекоммуникациях аналитические решения часто оказываются недостаточными. Поэтому используются численные методы.

Рассмотрим квадратурную формулу

$$\int_0^t \frac{\varphi(x) dx}{(t-x)^{1-\alpha}} \cong \sum_{\beta=0}^N C[\beta] \varphi(h\beta)$$

и соответственно ее функционал погрешности

$$\ell(x) = \varepsilon_{[0,t]}(x)(t-x)^{\alpha-1} - \sum_{\beta=0}^N C[\beta] \delta(x-h\beta)$$

в пространстве Соболева $L_2^{(m)}(0, t)$. Здесь $\varphi(x) \in L_2^{(m)}(0, t)$, $t > 0$ произвольное конечное число, $h = \frac{t}{N}$, $N \geq m$ натуральное число, $\delta(x)$ – дельта функция Дирака, $\varepsilon_{[0,t]}(x)$ – характеристическая функция отрезка $[0, t]$, $C[\beta]$ – коэффициенты квадратурных формул и $C[\beta] = 0$, при $h\beta \notin [0, t]$, $0 < \alpha < 1$.

Численные методы позволяют обрабатывать большие объёмы данных, моделировать реальные каналы связи, реализовывать алгоритмы в цифровых устройствах и повышать точность восстановления сигналов.

Особенно эффективными являются оптимальные квадратурные формулы, минимизирующие вычислительную погрешность.

Использование интегрального уравнения Абеля в телекоммуникациях обладает преимуществами, как возможность моделирования сложных процессов передачи сигнала, высокая точность восстановления информации, эффективность при обработке зашумлённых данных, универсальность применения в различных системах связи и возможность создания устойчивых алгоритмов цифровой обработки сигналов.

Заключение

Интегральное уравнение Абеля играет важную роль в современных задачах телекоммуникации и цифровой обработки сигналов. Благодаря своим математическим свойствам оно позволяет эффективно описывать процессы передачи информации, восстановления сигналов и фильтрации шумов.

Развитие вычислительных методов и цифровых технологий способствует дальнейшему расширению применения уравнений Абеля в радиосвязи, оптоволоконных системах и интеллектуальных телекоммуникационных сетях. Особенно перспективным направлением является разработка оптимальных квадратурных методов решения сингулярных интегральных уравнений для задач реального времени.

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OPTIMAL METHODS FOR APPROXIMATE CALCULATION OF RIEMANN-LIOUVILLE FRACTIONAL INTEGRALS

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We consider the quadrature formula

$$\int_0^t (t-x)^{\alpha-1} f(x) dx = \sum_{k=0}^n A_k f(x_k) + R_n f \quad (1)$$

for the approximate calculation of the left-sided Riemann-Liouville fractional order integral of the form (refer to [1])

$$D_{0,t}^{-\alpha} f(t) = {}_{RL} I_{0,t}^{\alpha} f(t) = \frac{1}{\Gamma(\alpha)} \int_0^t (t-x)^{\alpha-1} f(x) dx. \quad (2)$$

In this context, $\Gamma(\cdot)$ is Euler's gamma function, $t > 0$, $0 < \alpha < 1$, while A_k and x_k represent the coefficients and nodes of the quadrature formula (1), respectively, and $R_n(f)$ is the error of formula (1). Let us assume that the function $f(x)$ belongs to the Hilbert $W_2^{(1,0)}(0,t)$ space. Here, $W_2^{(1,0)}(0,t)$ is the Hilbert space of functions that are absolutely continuous and whose first-order derivative is square-integrable. For functions $f(x)$ and $g(x)$ from this space, the inner product is defined as:

$$\langle f(x), g(x) \rangle = \int_0^t (f'(x) + f(x))(g'(x) + g(x)) dx$$

and the corresponding norm is given by:

$$\|f(x)\| = \left(\int_0^t (f'(x) + f(x))^2 dx \right)^{\frac{1}{2}}.$$

One of the important problems in the theory of quadrature formulas is the optimality of quadrature formulas with respect to their error. In this work, we consider the problem of the optimality of the formula in the sense of Sard. In doing so, we utilize the method of φ -functions for constructing quadrature formulas.

Method of φ -functions. We consider the functions φ_k on each subinterval $[x_{k-1}, x_k]$, $k = 1, 2, \dots, n$, where φ_k satisfies the following condition for $k = 1, 2, \dots, n$:

$$\varphi'_k(x) - \varphi_k(x) = (t-x)^{\alpha-1}.$$

Then, the function φ is defined as follows:

$$\varphi|_{[x_{k-1}, x_k]} = \varphi_k(x), \quad k = 1, 2, \dots, n. \quad (3)$$

We introduce the following notations for the quadrature formula (1):

$$I(f) = \int_0^t (t-x)^{\alpha-1} f(x) dx, \quad (4)$$

$$Q_n(f) = \sum_{k=0}^n A_k f(x_k).$$

Theorem 1. *The coefficients of the optimal quadrature formula (2) are represented by the following expressions:*

$$\begin{cases} A_0 = -\varphi_1(x_0), \\ A_k = \varphi_k(x_k) - \varphi_{k+1}(x_k), \quad k = 1, \dots, n-1, \\ A_n = \varphi_n(x_n), \end{cases} \quad (5)$$

where $\varphi_k(x)$ are the functions satisfying the condition (3) for each subinterval $[x_{k-1}, x_k]$.

Proof. Using equality (3), we transform equality (4) into the following form:

$$\begin{aligned} I_{(0,t)}^\alpha(f) &= \int_0^t (t-x)^{\alpha-1} f(x) dx = \sum_{k=1}^n \int_{x_{k-1}}^{x_k} (\varphi'_k(x) - \varphi_k(x)) f(x) dx = \\ &= \varphi_n(x_n) \cdot f(x_n) + \sum_{k=1}^{n-1} \varphi_k(x_k) \cdot f(x_k) - \sum_{k=1}^{n-1} \varphi_{k+1}(x_k) \cdot f(x_k) - \varphi_1(x_0) f(x_0) - \sum_{k=1}^n \int_{x_{k-1}}^{x_k} \varphi_k(x) \cdot (f'(x) + f(x)) dx. \end{aligned}$$

From this, we have:

$$I(f) := -\varphi_1(x_0) \cdot f(x_0) + \sum_{k=1}^{n-1} (\varphi_k(x_k) - \varphi_{k+1}(x_k)) \cdot f(x_k) + \varphi_n(x_n) \cdot f(x_n) - \sum_{k=1}^n \int_{x_{k-1}}^{x_k} \varphi_k(x) \cdot (f'(x) + f(x)) dx$$

where $0 \leq x_0 < x_1 < \dots < x_n \leq t$.

The remainder term takes the following form:

$$R_n(f) = - \sum_{k=1}^n \int_{x_{k-1}}^{x_k} \varphi_k(x) \cdot (f'(x) + f(x)) dx.$$

Thus, we obtain the quadrature formula, as follows:

$$I(f) = -\varphi_1(x_0) \cdot f(x_0) + \sum_{k=1}^{n-1} (\varphi_k(x_k) - \varphi_{k+1}(x_k)) \cdot f(x_k) + \varphi_n(x_n) \cdot f(x_n) - \sum_{k=1}^n \int_{x_{k-1}}^{x_k} \varphi_k(x) \cdot (f'(x) + f(x)) dx. \quad (6)$$

After the transformations shown in (6), the remainder term $R_n(f)$ is separated, and the coefficients A_k are identified as the terms multiplying $f(x_k)$. Comparing this representation with the general form (2), this leads directly to the expressions for the coefficients given in (5).

Theorem 2. The exact values of the coefficients $A_0, A_k (k=1, 2, \dots, n-1)$, and A_n of the optimal quadrature formula are represented by the following expressions:

$$\begin{aligned} A_0 &= e^{x_0-t} \sum_{i=0}^{\infty} \frac{(t-x_0)^{i+\alpha}}{i!(i+\alpha)} + \frac{2e^{t+x_0}}{e^{2x_1} - e^{2x_0}} \sum_{i=0}^{\infty} \frac{1}{i!(i+\alpha)} \cdot \sum_{j=0}^{\infty} \frac{(-1)^j 2^j}{j!(i+j+\alpha+1)} \left[(t-x_1)^{i+j+\alpha+1} - (t-x_0)^{i+j+\alpha+1} \right] \\ A_k &= \frac{2e^{t+x_k}}{e^{2x_{k+1}} - e^{2x_k}} \sum_{i=0}^{\infty} \frac{1}{i!(i+\alpha)} \sum_{j=0}^{\infty} \frac{(-1)^j 2^j}{j!} \frac{1}{i+j+\alpha+1} \left[(t-x_{k+1})^{i+j+\alpha+1} - (t-x_k)^{i+j+\alpha+1} \right] \\ &\quad - \frac{2e^{t+x_k}}{e^{2x_k} - e^{2x_{k-1}}} \sum_{i=0}^{\infty} \frac{1}{i!(i+\alpha)} \sum_{j=0}^{\infty} \frac{(-1)^j 2^j}{j!} \frac{1}{i+j+\alpha+1} \left[(t-x_k)^{i+j+\alpha+1} - (t-x_{k-1})^{i+j+\alpha+1} \right] \\ A_n &= - \sum_{i=0}^{\infty} \frac{(t-x_n)^{i+\alpha}}{i!(i+\alpha)} - \frac{2e^{t+x_n}}{e^{2x_n} - e^{2x_{n-1}}} \sum_{i=0}^{\infty} \frac{1}{i!(i+\alpha)} \cdot \sum_{j=0}^{\infty} \frac{(-1)^j 2^j}{j!(i+j+\alpha+1)} \left[(t-x_n)^{i+j+\alpha+1} - (t-x_{n-1})^{i+j+\alpha+1} \right] \end{aligned}$$

Thus, the obtained results enable the practical application of optimal quadrature formulas and the construction of computational algorithms for the approximate calculation of Riemann-Liouville fractional integrals.

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ON A METHOD FOR CONSTRUCTING COMPOSITE OPTIMAL QUADRATURE FORMULAS IN THE HILBERT SPACE OF PERIODIC FUNCTIONS

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In recent years, several results based on the application of functional-theoretical concepts have been obtained in particular problems of computational mathematics. One can point to several problems in which functional-theoretical approaches yield general results: the construction of quadrature and cubature formulas, interpolation of functions of one and many variables, and the approximate solution of integral and differential equations (see [1]).

Of the listed questions, the question of approximate integral calculation has been developed in more detail than the others (see [2]). Let us consider a composite quadrature formula of the form:

$$\int_0^1 \varphi(x) dx \approx \sum_{\beta=0}^N \sum_{\gamma=0}^{m-1} C_{\beta\gamma} \varphi^\gamma(x_\beta) \quad (1)$$

here γ is from the Hilbert space $W_2^{(m,m-1)}$, $C_{\beta\gamma}$ are the coefficients of the quadrature formula, and $x_\beta \in [0, 1]$. Furthermore, we will consider the error of the quadrature formula as a linear functional of the form:

$$l(x) = \varepsilon_{[0,1]}(x) - \sum_{\beta=0}^N \sum_{\gamma=0}^{m-1} C_{\beta\gamma} \delta^\gamma(x - x_\beta) \quad (2)$$

in the space $W_2^{(m,m-1)}$ is classes of functions possessing generalized derivatives of order m with an integrable square and the norm:

$$\|\varphi\|_{W_2^{(m,m-1)}} = \left(\int_0^1 (\varphi^{(m)}(x) + \varphi^{(m-1)}(x))^2 dx \right)^{\frac{1}{2}} \quad (3)$$

where $\varepsilon_{[0,1]}(x)$ denotes the characteristic function of the interval $[0,1]$. The space $W_2^{(m,m-1)}$ is the class of periodic functions from $W_2^{(m,m-1)}$, i.e., $\varphi^{(\lambda)}(0) = \varphi^{(\lambda)}(1)$ for $\lambda = 0, 1, \dots, m-1$. Furthermore, $\int_0^1 \varphi(x) dx = 0$. Elements of the space $W_2^{(m,m-1)}$ are functions that differ from each other by a constant term. The norm of a function in the space of periodic functions $W_2^{(m,m-1)}$ is determined by the formula (1.3).

Theorem 1. Let $\varphi \in L_2^{(m)}$, then the following function:
 $\varphi^\sim = \varphi(x) - \int_0^1 \varphi(t) dt - \sum_{k=1}^m \frac{B_k(x)}{k!} (\varphi^{(k-1)}(1) - \varphi^{(k-1)}(0))$ is a periodic function in the space, i.e., an element of the space $W_2^{(m,m-1)}$, where $\varphi^{\sim(\lambda)}(0) = \varphi^{\sim(\lambda)}(1)$ for $\lambda = 0, 1, \dots, m-1$
 $\int_0^1 \varphi^\sim(x) dx = 0$

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A SYSTEM OF LINEAR ALGEBRAIC EQUATIONS FOR THE COEFFICIENTS OF OPTIMAL INTERPOLATION FORMULA

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Interpolation theory is one of the fundamental areas of numerical analysis and approximation theory. Classical interpolation formulas mainly use only function values, while many applied problems require the use of derivative values to achieve higher accuracy and smoothness. Interpolation formulas with derivatives are widely applied in solving differential equations, constructing smooth approximations, and numerical modeling.

Therefore, in the present work we study the construction of an optimal interpolation formula with derivatives in the Hilbert space $W_2^{(3,2)}(0,1)$. The interpolation formula uses the values of a function together with its first and second derivatives. The optimal coefficients are determined by minimizing the norm of the error functional. Using the variational approach and the method of Lagrange multipliers, a system of linear equations for the unknown coefficients is derived.

We consider the interpolation formula of the form:

$$P_\varphi(x) = \sum_{\beta=0}^N C_{\beta,0}(x)\varphi(x_\beta) + \sum_{\beta=0}^N C_{\beta,1}(x)\varphi'(x_\beta) + \sum_{\beta=0}^N C_{\beta,2}(x)\varphi''(x_\beta), \quad (1)$$

where $C_{\beta,0}(x)$ and $C_{\beta,1}(x)$ are known coefficients, while $C_{\beta,2}(x)$ are unknowns. Functions $\varphi(x)$ belong to the space $W_2^{(3,2)}(0,1)$.

The error of the interpolation formula (1) is given by

$$(R, \varphi) = \varphi(x) - P_\varphi(x) \quad (2)$$

The interpolation formula must satisfy the exactness conditions for the functions 1, x and e^{-x} . Under these conditions, the norm of the error functional depends on the coefficients $C_{\beta,2}(x)$. Among these exactness conditions, the unknown coefficients $C_{\beta,2}(x)$ appear only in the exactness condition for the function e^{-x} , which can be written in the following form:

$$(R, e^{-x}) = e^{-z} - \sum_{\beta=0}^N C_{\beta,0}e^{-x_\beta} + \sum_{\beta=0}^N C_{\beta,1}e^{-x_\beta} - \sum_{\beta=0}^N C_{\beta,2}e^{-x_\beta} = 0 \quad (3)$$

This relation plays a fundamental role in determining the optimal coefficients of the interpolation formula. Since the coefficients $C_{\beta,0}$ and $C_{\beta,1}$ are already known, the above condition provides the main constraint for finding the unknown coefficients $C_{\beta,2}$. Therefore, the main problem is to minimize this norm of the error functional R for the interpolation formula by coefficients and to determine the optimal coefficients.

To solve the minimization problem, the Sobolev extremal function method is applied, which satisfies [1]

$$(R, \psi_R) = \|R\|_{W_2^{(3,2)*}} \cdot \|\psi_R\|_{W_2^{(3,2)}}$$

After performing several calculations and applying the properties of the extremal function, we obtain the following representation for the extremal function [2]:

$$\psi_R(x) = G_3(x-z) - \sum_{\beta=0}^N C_{\beta,0}G_3(x-x_\beta) + \sum_{\beta=0}^N C_{\beta,1}G_3'(x-x_\beta) - \sum_{\beta=0}^N C_{\beta,2}G_3''(x-x_\beta) + c_1 + c_2x + de^{-x}. \quad (4)$$

Next, we derive the norm of the error functional R , whose representation is given in detail in [3]. The obtained norm expression is essential because it enables us to formulate the optimization problem and determine the unknown coefficients by minimizing the norm of the error functional.

To obtain the system of equations corresponding to the minimum of the error functional norm, we apply the method of Lagrange multipliers. Since the interpolation formula is required to satisfy the exactness condition (3), this condition is included in the minimization process through a Lagrange multiplier λ . Thus, we consider the following Lagrangian function

$$\Lambda(C_{\beta,2}, \lambda) = \|R\|_{W_2^{(3,2)}}^2 + \lambda(R, e^{-x}).$$

Because this norm represents a quadratic form with respect to the unknown coefficients $C_{\beta,2}$, the minimization problem can be solved by setting the partial derivatives of the function Λ with respect

to each coefficient equal to zero. By differentiating this functional with respect to the unknown coefficients, the following system of linear equations is obtained:

$$\sum_{\gamma=0}^N C_{\gamma,2} G_1(h\beta - h\gamma) + \lambda e^{-h\beta} = G_2(z - h\beta) - \sum_{\gamma=0}^N C_{\gamma,0} G_2(h\beta - h\gamma) + \sum_{\gamma=0}^N C_{\gamma,1} G_3''(h\beta - h\gamma),$$

$$\beta = 0, 1, \dots, N$$

Furthermore, differentiating the function Λ with respect to the Lagrange multiplier λ restores the exactness condition corresponding to the function e^{-x} :

$$\sum_{\beta=0}^N C_{\beta,2} e^{-h\beta} = e^{-z} - \sum_{\beta=0}^N C_{\beta,0} e^{-h\beta} + \sum_{\beta=0}^N C_{\beta,1} e^{-h\beta}$$

As a result, the minimization problem leads to the following complete system of linear equations:

$$\begin{cases} \sum_{\gamma=0}^N C_{\gamma,2} G_1(h\beta - h\gamma) + \lambda e^{-h\beta} = F(h\beta), & \beta = 0, 1, \dots, N, \\ \sum_{\beta=0}^N C_{\beta,2} e^{-h\beta} = G \end{cases} \quad (5)$$

where the functions $F(h\beta)$ and G are defined by the corresponding expressions.

The obtained system (5) has a unique solution. This follows from the positive definiteness of the kernel involved in the quadratic form and the nonsingularity of the corresponding matrix [4]. Therefore, the coefficients $C_{\beta,2}$ are uniquely determined.

As a result, the optimal interpolation formula with derivatives in the space $W_2^{(3,2)}(0,1)$ is completely characterized by the derived system of equations.

In this work, a theoretical framework for constructing optimal interpolation formulas with derivatives in a Hilbert space has been developed. The norm of the error functional was derived, and the minimization problem was solved using the method of Lagrange multipliers. Consequently, a complete system of linear equations for the optimal coefficients was obtained and its unique solvability was proved.

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FINDING THE HISTOSPLINE FUNCTION IN RECONSTRUCTING FUNCTIONS USING INTEGRAL VALUES IN THE SPACE $L_2^2(0,1)$

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In this work, we consider the problem of optimal approximation of a function in a space $L_2^2(0,1)$ with known integral values:

$$f(x) \cong P_f(x)$$

Suppose a function $f(x)$ belongs to the space $L_2^2(0,1)$ of functions with a square-integrable second derivative. At the same time, on the interval $[0,1]$

$$0 = x_0 < x_1 < \dots < x_n = 1$$

are nodes and on each subinterval $[x_{i-1}, x_i]$, the definite integral of the function $f(x)$

$$S_i = \int_{x_{i-1}}^{x_i} f(x) dx, \quad i = 1, 2, \dots, N$$

is known.

We find the sum of the histogram A_i as follows:

$$A_0 = 0$$

$$A_1 = S_1$$

$$A_2 = S_1 + S_2$$

...

$$A_N = S_1 + S_2 + \dots + S_N = \sum_{i=0}^N S_i$$

For the resulting set of points (x_n, A_n) , we construct a natural spline $Q_2(x)$ based on the algorithm in reference [1]:

$$Q_2(x) = \sum_{\gamma=0}^N C_\gamma \frac{|x - x_\gamma|^3}{12} + p_1 x + p_0$$

To find the histospline function, we take the derivative of the spline $Q_2(x)$ [2]:

$$f(x) \cong P_f(x) = \frac{d}{dx} Q_2(x)$$

As a result, we obtain the following quadratic function:

$$P_f(x) = \frac{d}{dx} Q_2(x) = \sum_{\gamma=0}^N C_\gamma \frac{(x - x_\gamma)^2 \operatorname{sgn}(x - x_\gamma)}{4} + p_1$$

The coefficients of the above histospline $P_f(x)$ have the following form:

$$C_0 = \frac{6}{h^3} [A_1 - 7A_0 - p_1^- h] + \frac{36\sqrt{3}}{h^3} \left[\sum_{\gamma=0}^N q_1^\gamma A_\gamma + M_1 + q_1^N N_1 \right]$$

$$C_\beta = \frac{6}{h^3} [A_{\beta-1} - 8A_\beta - A_{\beta+1}] + \frac{36\sqrt{3}}{h^3} \left[\sum_{\gamma=0}^N q_1^{|\beta-\gamma|} A_\gamma + q_1^\beta M_1 + q_1^{N-\beta} N_1 \right],$$

$\beta = 1, 2, \dots, N-1$

$$C_N = \frac{6}{h^3} [A_{N-1} - 7A_N + p_1^+ h] + \frac{36\sqrt{3}}{h^3} \left[\sum_{\gamma=0}^N q_1^{N-\gamma} A_\gamma + q_1^N M_1 + N_1 \right]$$

$$p_\alpha = \frac{1}{2} (p_\alpha^+ + p_\alpha^-), \quad \alpha = 0, 1,$$

where

$$\begin{aligned}
M_1 &= -p_1^- \frac{hq_1}{(1-q_1)^2} + p_0^- \frac{q_1}{1-q_1}, & N_1 &= p_1^+ \left(\frac{hq_1}{(1-q_1)^2} + \frac{q_1}{1-q_1} \right) + p_0^+ \frac{q_1}{1-q_1}, \\
p_0^- &= A_0, & p_0^+ &= A_N - p_1^+, \\
p_1^- &= \frac{T_1 A_{11}^+ - S_1 B_{11}^+}{B_{11}^- A_{11}^+ - A_{11}^- B_{11}^+}, & p_1^+ &= \frac{S_1 B_{11}^- - T_1 A_{11}^-}{B_{11}^- A_{11}^+ - A_{11}^- B_{11}^+}, \\
B_{11}^- &= h(7q_1 + 2), & B_{11}^+ &= -h\sqrt{3}q_1^{N+2}, \\
A_{11}^- &= h\sqrt{3}q_1^{N+2}, & A_{11}^+ &= -h(7q_1 + 2), \\
T_1 &= -6\sqrt{3}q_1^2 \sum_{\gamma=0}^N q_1^\gamma A_\gamma + A_0(2q_1 + 1)(1 - q_1) + A_N \sqrt{3}q_1^{N+2}(1 - q_1), \\
S_1 &= -6\sqrt{3}q_1^2 \sum_{\gamma=0}^N q_1^{N-\gamma} A_\gamma + A_0 \sqrt{3}q_1^{N+2}(1 - q_1) + A_N(2q_1 + 1)(1 - q_1), \\
q_1 &= \sqrt{3} - 2.
\end{aligned}$$

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GILBERT FAZOSIDA PHI FUNKSIYA METODI YORDAMIDA IXTIYORIY TUGUN NUQTALI KVADRATUR FORMULA QURISH

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Biz ushbu ishda $W_{2,\sigma}^{(m,m-1)}(a,b)$ fazosida hosilali kvadratur formulalar qurish masalasini ko'rib chiqamiz.

Quyidagi ko'rinishdagi kvadratur formulani qaraymiz:

$$\int_a^b f(x)dx = \sum_{k=0}^n \sum_{j=0}^{m-1} A_{kj} f^{(j)}(x_k) + R_n(f), \quad (1)$$

bu yerda A_{kj} -kvadratur formulaning koeffitsiyentlari va x_k -lar tugun nuqtalar. Tugun nuqtalar $[a,b]$ kesmada quyidagicha joylashgan deb hisoblaymiz

$$a = x_0 < x_1 < \dots < x_n = b, \quad (2)$$

$R_n(f)$ -(1) formulaning xatoligi.

Mazkur ishda $W_{2,\sigma}^{(m,m-1)}(a,b)$ fazoda Sard ma'nosida (1) ko'rinishdagi optimal kvadratur formulani qurish masalasi yechiladi, ya'ni fiksirlangan X tugunlar uchun $F_n(W_{2,\sigma}^{(m,m-1)}, A) = \sup_{f \in W_{2,\sigma}^{(m,m-1)}} |R_n(f)|$ miqdorga eng kichik qiymat beradigan (1) formula

koeffitsiyentlarini topish ko'zda tutiladi. Bunda φ -funksiyalar metodidan foydalaniladi.

Endi har bir $[x_{k-1}, x_k]$, $k = 1, 2, \dots, n$ intervalda quyidagi xossaga ega bo'lgan φ_k , $k = 1, 2, \dots, n$ funksiyalarni qaraymiz:

$$(-1)^m \varphi_k^{(m)}(x) + (-1)^{m-1} \sigma \varphi_k^{(m-1)}(x) = 1, \quad k = 1, 2, \dots, n. \quad (3)$$

Shundan so'ng φ funksiya quyidagicha aniqlanadi:

$$\varphi|_{[x_{k-1}, x_k]} = \varphi_k(x), \quad k=1, 2, \dots, n. \quad (4)$$

Ya'ni, φ funksiya $[x_{k-1}, x_k]$ oraliqda φ_k ga teng bo'ladi.

Kvadratur formulaning optimalligi masalasi

Kvadratur formulaning (1) uchun $R_n(f)$ xatolikning absolyut qiymatiga Koshi-Shvarz tengsizligini qo'llab, quyidagi bahoga ega bo'lamiz:

$$|R_n(f)| \leq \|f(x)\|_{W_{2,\sigma}^{(m,m-1)}} \|\varphi(x)\|_{L_2(a,b)}. \quad (5)$$

Kvadratur formulaning $A = (A_0, A_1, \dots, A_n)$ optimal koeffitsiyentlarni shunday aniqlashdan iboratki, bunda

$$F_n(A) = \int_a^b \varphi^2(x) dx. \quad (6)$$

miqdor eng kichik qiymatga ega bo'lsin.

Keyin (3) differensial tenglamaning umumiy yechimini topamiz. U quyidagi ko'rinishda:

$$\varphi(x) = C_1 + C_2 x + C_3 x^2 + \dots + C_{m-1} x^{m-2} + C_m e^{\sigma x} + \frac{(-1)^{m+1} x^{m-1}}{\sigma(m-1)!} \quad (7)$$

Endi biz ushbu normaga minimum beruvchi C_i larni topamiz.

$$\begin{aligned} F(\varphi_k(x)) &= \int_{x_{k-1}}^{x_k} (\varphi_k(x))^2 dx = \int_{x_{k-1}}^{x_k} \left(\sum_{i=1}^{m-1} C_i x^{i-1} + C_m e^{\sigma x} + \frac{(-1)^{m+1} x^{m-1}}{\sigma(m-1)!} \right)^2 dx. \\ \left\{ \begin{aligned} \frac{\partial F(\varphi_k)}{\partial C_m} &= 0, & 2 \int_{x_{k-1}}^{x_k} e^{\sigma x} \left(\sum_{i=1}^{m-1} C_i x^{i-1} + C_m e^{\sigma x} + \frac{(-1)^{m+1} x^{m-1}}{\sigma(m-1)!} \right) dx &= 0, \\ \frac{\partial F(\varphi_k)}{\partial C_{m-1}} &= 0, & 2 \int_{x_{k-1}}^{x_k} x^{m-2} \left(\sum_{i=1}^{m-1} C_i x^{i-1} + C_m e^{\sigma x} + \frac{(-1)^{m+1} x^{m-1}}{\sigma(m-1)!} \right) dx &= 0, \\ \dots & \dots \\ \frac{\partial F(\varphi_k)}{\partial C_2} &= 0, & 2 \int_{x_{k-1}}^{x_k} x \left(\sum_{i=1}^{m-1} C_i x^{i-1} + C_m e^{\sigma x} + \frac{(-1)^{m+1} x^{m-1}}{\sigma(m-1)!} \right) dx &= 0, \\ \frac{\partial F(\varphi_k)}{\partial C_1} &= 0. & 2 \int_{x_{k-1}}^{x_k} 1 \left(\sum_{i=1}^{m-1} C_i x^{i-1} + C_m e^{\sigma x} + \frac{(-1)^{m+1} x^{m-1}}{\sigma(m-1)!} \right) dx &= 0. \end{aligned} \right. \quad (8) \end{aligned}$$

Tenglamalar sistemasidan topilgan C_i larni (7) ga qo'yib $\varphi(x)$ funksiyaning aniq ko'rinishini topamiz. Mos ravishda Kvadratur formula koeffitsiyentlari quyidagicha topiladi.

$m=1$ holat uchun

$$\begin{aligned} A_{0j} &= (-1)^{(m-j+1)} \varphi_1^{(m-j-1)}(x_0) \\ A_{kj} &= (-1)^{(m+j)} [\varphi_k - \varphi_{k+1}]^{(m-j-1)}(x_k) \quad k=1, \dots, n-1, \quad j=0, \dots, m-1. \\ A_{nj} &= (-1)^{(m+j)} \varphi_n^{(m-j-1)}(x_n) \end{aligned}$$

$m=2$ holat dan boshlab quyidagicha

$$\begin{aligned} A_{0j} &= (-1)^{(m-j+1)} \varphi_1^{(m-j-1)}(x_0) + (-1)^{(m+j)} \sigma \varphi_1^{(m-j-2)}(x_0) \\ A_{kj} &= (-1)^{(m+j)} [\varphi_k - \varphi_{k+1}]^{(m-j-1)}(x_k) + (-1)^{(m+j-1)} \sigma [\varphi_k - \varphi_{k+1}]^{(m-j-2)}(x_k) \\ & \quad k=1, \dots, n-1, \quad j=0, \dots, m-2. \\ A_{nj} &= (-1)^{(m+j)} \varphi_n^{(m-j-1)}(x_n) + (-1)^{(m+j-1)} \sigma \varphi_n^{(m-j-2)}(x_n) \end{aligned}$$

К ВОПРОСУ О ПЕРЕХОДЕ МЕЖДУ ПРЯМОУГОЛЬНОЙ И КРУГОВОЙ КОМПЛЕКСНЫМИ ИНТЕРВАЛЬНЫМИ АРИФМЕТИКАМИ

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Аннотация. Рассмотрены две формы комплексной интервальной арифметики — прямоугольная и круговая. Проанализированы их основные операции: сложение, вычитание, умножение, деление. Показано, что переход между представлениями необходим в гибридных алгоритмах, но приводит к консервативному расширению множества. Выбор оптимальной стратегии перехода остаётся открытым вопросом.

Интервальный анализ, зародившийся в работах R.E.Moore в 1960-х годах [1], традиционно фокусировался на вещественных интервалах. Однако многие прикладные задачи — от цифровой обработки сигналов до вычисления комплексных корней полиномов — естественным образом оперируют с комплексными числами, что привело к развитию *комплексных интервальных арифметик* [2]. Сегодня существует несколько конкурирующих подходов к представлению комплексных интервалов, и выбор подходящей арифметики остаётся нетривиальной задачей, напрямую влияющей на точность и эффективность вычислений.

Наиболее распространёнными являются *прямоугольная комплексная интервальная арифметика* $\mathbb{IC}_{rect}$, представляющая неопределённость в виде декартова произведения вещественных интервалов, и *круговая интервальная арифметика* $\mathbb{IC}_{circ}$, задающая область в виде круга на комплексной плоскости [2, 3] (см. рис. 1).

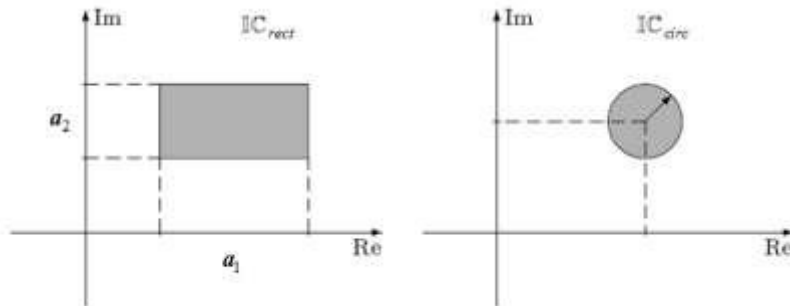


Рис. 1. Прямоугольные и круговые интервалы на комплексной плоскости.

Для формального анализа последствий перехода между двумя типами комплексной интервальной арифметики необходимо детально рассмотреть их основные арифметические операции. Ниже приводятся определения сложения, вычитания, умножения, деления и сопряжения для прямоугольной $\mathbb{IC}_{rect}$ и круговой $\mathbb{IC}_{circ}$ форм.

1. Прямоугольная комплексная интервальная арифметика.

Основные арифметические операции в прямоугольной комплексной интервальной арифметике [4] для $\mathbf{x} = [\underline{x}_1, \bar{x}_1] + i[\underline{x}_2, \bar{x}_2] \in \mathbb{IC}_{rect}$ и $\mathbf{y} = [\underline{y}_1, \bar{y}_1] + i[\underline{y}_2, \bar{y}_2] \in \mathbb{IC}_{rect}$ определяется следующим образом (напомним, что интервальные величины по соглашению [5] выделяются жирно-курсивным шрифтом):

Сложение. $\mathbf{x} + \mathbf{y} = [\underline{x}_1 + \underline{y}_1, \bar{x}_1 + \bar{y}_1] + i[\underline{x}_2 + \underline{y}_2, \bar{x}_2 + \bar{y}_2]$.

Вычитание. При вычитании границы меняются местами для сохранения включения: $\mathbf{x} - \mathbf{y} = \mathbf{x} + (-\mathbf{y})$, где $-\mathbf{y} = [-\bar{y}_1, -\underline{y}_1] + i[-\bar{y}_2, -\underline{y}_2]$. Таким образом

$\mathbf{x} - \mathbf{y} = [\underline{x}_1 - \bar{y}_1, \bar{x}_1 - \underline{y}_1] + i[\underline{x}_2 - \bar{y}_2, \bar{x}_2 - \underline{y}_2]$.

Умножение. Для компактности введём множества произведений границ, с учётом вещественную и мнимую части результата:

$$\begin{aligned}
P_{RR} &= \{x_1 y_1, x_1 \bar{y}_1, \bar{x}_1 y_1, \bar{x}_1 \bar{y}_1\}, \\
P_{II} &= \{x_2 y_2, x_2 \bar{y}_2, \bar{x}_2 y_2, \bar{x}_2 \bar{y}_2\}, \\
P_{RI} &= \{x_1 y_2, x_1 \bar{y}_2, \bar{x}_1 y_2, \bar{x}_1 \bar{y}_2\}, \\
P_{IR} &= \{x_2 y_1, x_2 \bar{y}_1, \bar{x}_2 y_1, \bar{x}_2 \bar{y}_1\}.
\end{aligned}$$

Тогда:

$$x \cdot y = [\min P_{RR} - \max P_{II}, \max P_{RR} - \min P_{II}] + i [\min P_{RI} + \min P_{IR}, \max P_{RI} - \max P_{IR}].$$

Деление. Пусть $y \neq 0$ в том смысле, что нуль как комплексное число не принадлежит интервалу y , т.е. $0 \notin [y_1, \bar{y}_1]$ или $0 \notin [y_2, \bar{y}_2]$ (достаточно, чтобы хотя бы одна компонента не содержала нуля).

Тогда деление определяется как:

$$x / y = x \cdot y^{-1},$$

где $y^{-1} = \frac{y^*}{|y|^2}$, при условии, что $|y|^2$ не содержит нуля (т.е. $0 \notin |y|^2$), что гарантируется $y \neq 0$

в указанном выше смысле.

Здесь $y^* = [y_1, \bar{y}_1] - i[y_2, \bar{y}_2]$ — комплексное сопряжение,

$y^* = y \cdot y^* = [y_1, \bar{y}_1]^2 + [y_2, \bar{y}_2]^2 \in \mathbb{IR}_+$ - вещественный интервальный квадрат модуля.

2. Круговая комплексная интервальная арифметика.

В отличие от прямоугольной формы, представляющей неопределённость в виде декартова произведения вещественных интервалов, круговая комплексная интервальная арифметика описывает множество возможных значений в виде круга на комплексной плоскости. Такое представление оказывается особенно удобным для операций умножения, деления и возведения в степень, поскольку эти операции в комплексной плоскости естественным образом отображают круги в круги (или в множества, хорошо аппроксимируемые кругами).

Круговой комплексный интервал (далее — круг) определяется центром и радиусом:

$$a = \langle a, r_a \rangle = \{z \in \mathbb{C} : |z - a| \leq r_a\},$$

где $a \in \mathbb{C}$ — центр круга, $r_a \in \mathbb{IR}_+$ — радиус.

Для двух кругов $a = \langle a, r_a \rangle$ и $b = \langle b, r_b \rangle$ определим основные арифметические операции.

Сложение. Сложение двух кругов выполняется как сумма по Минковскому:

$$a + b = \langle a + b, r_a + r_b \rangle.$$

Вычитание. Вычитание сводится к сложению с противоположным кругом $-b = \langle -b, r_b \rangle$:

$$a - b = \langle a - b, r_a + r_b \rangle.$$

Умножение. Умножение кругов — нетривиальная операция. Оптимальная (наименьший круг, содержащий все произведения) форма имеет вид:

$$a \cdot b = \langle a \cdot b, |a| r_b + |b| r_a + r_a r_b \rangle.$$

Если один из кругов содержит нуль, формула может давать неоптимальное расширение; в таких случаях рекомендуется дополнительный анализ.

Деление. Деление a / b определено при условии, что нуль не принадлежит b , т.е. $r_b < |b|$.

Тогда:

$$\frac{a}{b} = \left\langle \frac{a}{b}, \frac{|a|r_b + |b|r_a + r_a r_b}{|b|^2 - r_b^2} \right\rangle.$$

Здесь, как частный случай деления при $a = \langle 1, 0 \rangle$:

$$b^{-1} = \left\langle \frac{b^*}{|b|^2 - r_b^2}, \frac{r_b}{|b|^2 - r_b^2} \right\rangle,$$

где b^* - комплексное сопряжение центра b .

Каждая из этих форм обладает принципиальными преимуществами: прямоугольная форма точна при сложении и пересечении множеств, тогда как круговая форма оказывается незаменимой при умножении, делении и вычислении обратных величин [3, 6].

Проблема в этом направлении, остающаяся открытой, заключается в следующем: ни одна из этих форм не является универсально оптимальной для всех операций. В вычислительных алгоритмах, где чередуются сложение и умножение (например, при вычислении значений полиномов или в итерационных методах поиска корней), возникает необходимость перехода от одного представления к другому [2]. Однако такие переходы сопряжены с потерей информации и, как правило, приводят к консервативному расширению оцениваемого множества.

Вопрос о том, когда и как следует переходить от одного типа комплексной интервальной арифметики к другому, остаётся малоисследованным, вообще говоря, открытым. В литературе отсутствуют систематические рекомендации по выбору стратегии переключения между прямоугольными и круговыми формами в зависимости от структуры вычислительного графа. Данная работа направлена на анализ этой проблемы: мы рассмотрим формальные основы перехода между представлениями, оценим его влияние на точность вычислений и наметим перспективные подходы к построению гибридных алгоритмов, автоматически выбирающих оптимальную форму представления.

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ПРЕОДОЛЕНИЕ ЭФФЕКТА ЗАВИСИМОСТИ В ИНТЕРВАЛЬНЫХ ВЫЧИСЛЕНИЯХ: ПЕРЕХОД ОТ КЛАССИЧЕСКОЙ ИНТЕРВАЛЬНОЙ АРИФМЕТИКИ К АФФИННОЙ

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Аннотация. В данной работе проводится сравнительный анализ двух методов на наглядных примерах. Демонстрируются ключевые недостатки классической ИА, связанные с потерей точности в задачах с многократными вхождениями переменных, и показывается эффективность аффинной арифметики в получении более узких и содержательных оценок.

1. Введение.

Интервальный анализ является фундаментальным инструментом для учета неопределенностей и гарантированного контроля ошибок вычислений. Классическая интервальная арифметика (КИА) обеспечивает надежную верификацию результатов, однако её практическое применение часто ограничено эффектом избыточного расширения интервалов, так называемое “dependency problem” и игнорированием корреляций между переменными. Это приводит к экспоненциальному росту ширины результирующих интервалов даже в простых вычислительных цепочках, делая оценку тривиальной и бесполезной.

Аффинная арифметика (АА) устраняет указанные ограничения, сохраняя информацию о линейных зависимостях между неопределенными величинами на протяжении всего процесса вычислений. В отличие от классического подхода, АА оперирует символьным представлением погрешности, что позволяет существенно подавлять эффект «разбухания» границ.

2. Недостатки КИА.

КИА задается как алгебраическая система $\langle \mathbb{IR}, +, -, \cdot, / \rangle$, с бинарными арифметическими операциями для вещественных интервалов $\mathbf{a} = [\underline{a}, \bar{a}]$ и $\mathbf{b} = [\underline{b}, \bar{b}]$:

$$\mathbf{a} * \mathbf{b} = \{a * b \mid a \in \mathbf{a}, b \in \mathbf{b}\}, \quad (1)$$

где $*$ $\in \{+, -, \cdot, /\}$, также можно записать по отдельным операциям в следующем виде:

- $\mathbf{a} + \mathbf{b} = [\underline{a} + \underline{b}, \bar{a} + \bar{b}]$
- $\mathbf{a} - \mathbf{b} = [\underline{a} - \bar{b}, \bar{a} - \underline{b}]$
- $\mathbf{a} \cdot \mathbf{b} = [\min\{\underline{a} \cdot \underline{b}, \underline{a} \cdot \bar{b}, \bar{a} \cdot \underline{b}, \bar{a} \cdot \bar{b}\}, \max\{\underline{a} \cdot \underline{b}, \underline{a} \cdot \bar{b}, \bar{a} \cdot \underline{b}, \bar{a} \cdot \bar{b}\}]$
- $\mathbf{a} / \mathbf{b} = \mathbf{a} \cdot (1 / \mathbf{b}) = \mathbf{a} \cdot (1 / [\underline{b}, \bar{b}]) = \mathbf{a} \cdot [1 / \bar{b}, 1 / \underline{b}]$, given that $0 \notin \mathbf{b}$.

Основным недостатком КИА (1) является то, что в ней отсутствуют обратные элементы относительно операциям сложения и умножения: в общем случае

$$(\mathbf{a} + \mathbf{b}) - \mathbf{b} \neq \mathbf{a}, \quad (\mathbf{a} \cdot \mathbf{b}) / \mathbf{b} \neq \mathbf{a}.$$

Кроме того не выполняется свойство дистрибутивности $\mathbf{a} \cdot (\mathbf{b} + \mathbf{c}) \neq \mathbf{a} \cdot \mathbf{b} + \mathbf{a} \cdot \mathbf{c}$, но существует свойство, которое всегда выполняется для любых интервалов, и оно называется «субдистрибутивность»: $\mathbf{a} \cdot (\mathbf{b} + \mathbf{c}) \subseteq \mathbf{a} \cdot \mathbf{b} + \mathbf{a} \cdot \mathbf{c}$.

Только в некоторых случаях закон дистрибутивности сохраняется.

$$\text{if } a \in \mathbb{R} \text{ and } \mathbf{b}, \mathbf{c} \in \mathbb{IR} \Rightarrow a \cdot (\mathbf{b} + \mathbf{c}) = \mathbf{a} \cdot \mathbf{b} + \mathbf{a} \cdot \mathbf{c};$$

$$\text{if } b, c \in \mathbb{R}, \mathbf{a} \in \mathbb{IR} \text{ and } \{b, c \geq 0, \text{ or } b, c \leq 0\} \Rightarrow \mathbf{a} \cdot (b + c) = \mathbf{a} \cdot b + \mathbf{a} \cdot c.$$

КИА заменяет каждую неопределённую величину интервалом $\mathbf{x} = [\underline{x}, \bar{x}]$ и определяет операции покомпонентно: результат операции гарантированно содержит все возможные исходы. Однако платой за эту гарантию становится систематическое завышение оценки неопределённости. Причина — утрата информации о связях между величинами.

В существующих литературах отмечают, что классическая интервальная арифметика даёт хорошие внешние оценки, когда оперируемые переменные независимы и если они в арифметических выражениях встречаются не более одного раза. В противном случае, приводит к завышению интервальной оценки, что является неприятным случаем. В следующем примере представлен один из таких случаев (Пример 1).

Пример 1. Пусть задана рациональная функция [1]: $f(x, y) = xy - x + 3$ и переменные принимают значения $x \in [0, 1]$, $y \in [1, 2]$. Тогда интервальная оценка области значений

$$f(\mathbf{x}, \mathbf{y}) = \mathbf{x} \cdot \mathbf{y} - \mathbf{x} + 3 = [0, 1] \cdot [1, 2] - [0, 1] + 3 = [2, 5].$$

Если переписать выражение как $f(\mathbf{x}, \mathbf{y}) = \mathbf{x} \cdot (\mathbf{y} - 1) + 3$, то приводит нас к интервалу $[0, 1] \cdot ([1, 2] - 1) + 3 = [3, 4]$, в три раза более узкому.

Таким образом, при интервальном оценивании имеет смысл рассуждать не в терминах функций, а в терминах их выражений. Именно поэтому многие исследователи пытаются усовершенствовать арифметические выражения, например, в [2].

В интервальном анализе особо отмечаются независимые и связанные интервалы. Для иллюстрации независимых и связанных интервалов приведем следующий пример (Пример 2).

Пример 2. Пусть $x_1 = x_2 = [0, 2]$. Если эти интервалы независимы друг с другом, то их совместная область S_1 является прямоугольником, что совпадает прямым декартовым произведением $x_1 \times x_2$ (Рис. 1 (a)). Если для всех представителей $\forall x_1 \in x_1, \forall x_2 \in x_2$, наложены какие-то связи, например, как $1 \leq x_1 + x_2 \leq 2$, то их совместная область S_2 представляет собой более узкую трапециевидную фигуру (Рис. 1 (b)).

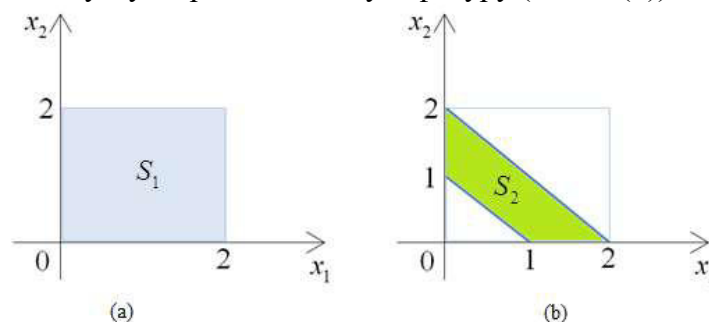


Рис. 1. Геометрическая интерпретация независимых (a) и связанных (b) интервалов.

Связанные интервалы часто встречаются на практике, например, при решении оптимизационных задач с заданными ограничениями.

Таким образом, при решении большинство прикладных задач мы чаще сталкиваемся с феноменом зависимости параметров. Но КИА, а также некоторые другие простые инструменты интервального анализа могут быть использованы только для обработки именно независимых величин. Такие недостатки в задачах со связанными данными приходится компенсировать разнообразными способами. Одним из популярных инструментов для вычислений с множествами, который учитывает взаимные связи и зависимость величин, является так называемая аффинная арифметика [3, 4]. В ней области совместных значений переменных операндов приближаются с помощью многогранников специального вида, и информация о них сохраняется и далее используется в процессе вычислений.

3. Аффинная арифметика: сохранение зависимостей.

Аффинная арифметика представляет каждую неопределённую величину $\hat{x}$ как линейную комбинацию независимых символьных переменных — шумовых компонент $\varepsilon_k \in [-1, 1]$:

$$\hat{x} = x_0 + x_1\varepsilon_1 + x_2\varepsilon_2 + \dots + x_n\varepsilon_n.$$

Здесь x_0 — центральное значение, x_k ($k = 1, 2, \dots, n$) — амплитуды частных погрешностей. Одна и та же компонента ε_k используется во всех величинах, которые от неё зависят. Это позволяет явно сохранять корреляции (Пример 3).

Пример 3. Пусть $x \in [1, 2]$. Рассмотрим выражение $f(x) = x - x$. Математически результат равен нулю при любом x . Применение КИА даёт:

$$f([1, 2]) = [1, 2] - [1, 2] = [-1, 1].$$

Применяем АА:

$$\hat{x} = 1.5 + 0.5\varepsilon_1 \Rightarrow f(\hat{x}) = \hat{x} - \hat{x} = (1.5 + 0.5\varepsilon_1) - (1.5 + 0.5\varepsilon_1) = 0 = [0, 0].$$

Интервальная оценка результата: $[0, 0]$ — точный ответ, ошибка КИА устранена. Обе переменные «помнят», что они порождены одним источником ε_1 , и взаимно уничтожаются.

4. Сравнительный анализ результатов.

Сопоставим оценки КИА и АА на рассмотренных примерах.

Таблица 1. Сравнительный анализ оценки КИА и АА.

Задача	Истинный диапазон	КИА	АА
$x - x, x \in [1, 2]$	$[0, 0]$	$[-1, 1]$	$[0, 0]$
$x(1-x), x \in [0, 1]$	$[0, 0.25]$	$[0, 1]$	$[0, 0.25] + \delta$
$xy - x + 3, x \in [0, 1], y \in [1, 2]$	$[3, 4]$	$[2, 5]$	$[3, 4] + \delta$

Символ δ обозначает малый добавочный интервал, возникающий в АА при аппроксимации нелинейных операций. Умножение двух аффинных форм $\hat{x} \cdot \hat{y}$ содержит квадратичное слагаемое $(\sum x_k \varepsilon_k)(\sum y_k \varepsilon_k)$. АА заменяет его линейной оценкой плюс новая независимая шумовая компонента ε_{new} , моделирующая погрешность линеаризации. Ширина δ пропорциональна произведению суммарных амплитуд шумов сомножителей. Например, для задачи $xy - x + 3, x \in [0, 1], y \in [1, 2]$ типичное значение $\delta \approx [-0.25, 0.25]$, что на порядок меньше переоценки КИА.

Таким образом, АА полностью устраняет ошибку, вызванную многократным вхождением переменной (эффект зависимости), и существенно замедляет накопление погрешности при итерациях (эффект обёртывания).

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CONSTRUCTION OF OPTIMAL QUADRATURE FORMULAS IN THE SPACE $L_2^{(3)}(a, b)$

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The computation of definite integrals plays a fundamental role in applied mathematics, physics, and engineering sciences. However, in many practical applications, obtaining exact analytical solutions is often impossible due to the complexity of the integrand or the absence of a closed-form representation. For such cases, numerical integration methods, especially quadrature formulas, provide powerful and efficient tools for approximating definite integrals using function values and derivative information at carefully chosen nodes.

The construction and analysis of quadrature formulas remain important problems in numerical analysis. In this work, we focus on the determination of optimal coefficients of a quadrature formula in the Sobolev space $L_2^{(3)}(a, b)$. Furthermore, we establish an upper bound for the error functional associated with the proposed quadrature formula, which allows us to evaluate the accuracy and efficiency of the approximation method.

We focus on a quadrature formula of the form:

$$\int_a^b \frac{f(x)}{\sqrt{x-a}} dx = \sum_{k=0}^n (A_{0k} f(x_k) + A_{1k} f'(x_k) + A_{2k} f''(x_k)) + R_n(f), \quad (1)$$

where x_k are the quadrature nodes, A_{0k}, A_{1k}, A_{2k} are unknown coefficients, and $R_n(f)$ is the error of the quadrature formula.

The coefficients are found using the φ -function method. Using this approach, the quadrature formula is constructed in the sense of Sard, ensuring that the error functional attains its minimum in the space $L_2^{(3)}(a, b)$.

The principal result of this study is presented in the following theorem.

Theorem 1. In the space $L_2^{(3)}(a, b)$, for each fixed positive integer n , there is a quadrature formula that is optimal in the sense of Sard [1, 2] of the form:

$$\int_a^b \frac{f(x)}{\sqrt{x-a}} dx = \sum_{k=0}^n (A_{0k} f(x_k) + A_{1k} f'(x_k) + A_{2k} f''(x_k)) + R_n(f)$$

with coefficients

$$\begin{cases} A_{00} = -\varphi_1''(x_0) \\ A_{0k} = -\varphi_{k+1}''(x_k) + \varphi_k''(x_k) \\ A_{0n} = \varphi_n''(x_n) \\ A_{10} = \varphi_1'(x_0) \\ A_{1k} = \varphi_{k+1}'(x_k) - \varphi_k'(x_k) \\ A_{1n} = -\varphi_n'(x_n) \\ A_{20} = -\varphi_1(x_0) \\ A_{2k} = \varphi_k(x_k) - \varphi_{k+1}(x_k), \quad k = 1, \dots, n-1 \\ A_{2n} = \varphi_n(x_n) \end{cases}$$

for fixed nodes x_k satisfying the inequality

$$a = x_0 < x_1 < \dots < x_n = b.$$

The φ -function method provides a structured approach for deriving the coefficients in explicit form and for obtaining an analytical representation of the error term. Such quadrature formulas can be effectively applied in numerical integration, the solution of differential equations, and various problems arising in applied mathematical modeling. In our future research, we plan to determine the exact values of the coefficients and, based on them, construct the function φ and the remainder term $R_n(f)$.

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HIGH-ACCURACY NUMERICAL SOLUTIONS OF SINGULARLY PERTURBED EQUATIONS BASED ON A DISCRETE VARIANT OF THE PRELIMINARY INTEGRATION METHOD

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Abstract: In the present paper, a second-order singularly perturbed equation is numerically investigated using a discrete variant of the preliminary integration method. The conducted numerical experiments demonstrate that the proposed method possesses high accuracy and computational efficiency. Furthermore, the significant reduction in the absolute errors between the exact and approximate solutions confirms the effectiveness and stability of the method.

We consider a boundary value problem formulated for the following second-order singularly perturbed differential equation:

$$4\varepsilon \frac{d^2 y}{dx^2} + 2(\varepsilon + 1) \frac{dy}{dx} + y(x) = 0, \quad y \in [-1, 1], \quad (1)$$

$$y(-1) = 0, \quad y(1) = 1, \quad (2)$$

here, ε – small parameter ($0 < \varepsilon < 1$).

For problem (1)– (2), the exact solution is chosen as follows [1]:

$$y_e(x) = \frac{e^{-(x+1)/2\varepsilon} - e^{-(x+1)/2}}{e^{-1/\varepsilon} - e^{-1}}, \quad y_e = y_{exact}. \quad (3)$$

This function fulfills the conditions specified by the equations (1)– (2).

To numerically modeling the differential problem (1)– (2), we utilize a discrete variant of the preliminary integration method. The approximate solution y_a is represented in the form of a first-kind Chebyshev polynomial series as follows [2-5]:

$$\frac{dy_a}{dx} = \sum_{i=0}^N ' a_i T_i(x). \quad (4)$$

In this formulation, a_i -is an unknown coefficient and a prime on the summation $i=0$ indicates that the coefficient $\frac{1}{2}$ is taken together with the corresponding multiplier. For computing the second-order derivative, the following relation is applied:

$$\frac{d^2 y_a}{dx^2} = \sum_{i=0}^N ' a_i^{(2x)} T_i(x). \quad (5)$$

By substituting equations (4)– (5) into equation (1),

$$4\varepsilon \sum_{i=0}^N ' a_i^{(2x)} T_i(x) + 2(1+\varepsilon) \sum_{i=0}^N ' a_i^{(x)} T_i(x) + \sum_{i=0}^N ' a_i T_i(x) = 0,$$

we obtain the following equation.

From the resulting expression, we derive the following equation:

$$4\varepsilon a_i^{(2x)} + 2(1+\varepsilon) a_i^{(x)} + a_i = 0.$$

Applying the discrete formula of the initial integration method

$$a_i^{((k-1)x)} = \frac{a_{i-1}^{(kx)} - a_{i+1}^{(kx)}}{2i}, \quad (6)$$

to both sides of this equation, we perform two consecutive integrations. By adding and subtracting the equations derived from the boundary conditions (2), we obtain the following system of equations.

$$\begin{cases} (i+1)a_{i-2} + 4(1+\varepsilon)(i^2-1)a_{i-1} + (16\varepsilon i(i^2-1) - 2i)a_i - \\ - 4(1+\varepsilon)(i^2-1)a_{i+1} + (i-1)a_{i+2} = 0, \quad (i=2, 3, \dots, N) \\ \frac{1}{2}a_0 + a_2 + a_4 + \dots + a_N = \frac{1}{2}, \\ a_1 + a_3 + a_5 + \dots + a_{N-1} = \frac{1}{2}. \end{cases} \quad (7)$$

The system of algebraic equations (7) was numerically solved and the following results were obtained. By solving the system of algebraic equations (7) for a_i and substituting them into the approximate solution formula (4), we compute the values of the approximate solution at the

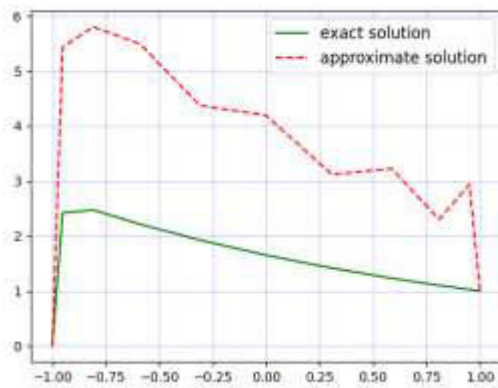
$x_l = \cos \frac{\pi l}{N}$, $l = 0, 1, 2, \dots, N$ nodal points. To illustrate the high accuracy of the proposed method, the maximum absolute errors of the approximate solution at the collocation nodes of the polynomials x_l ($l = 0, 1, 2, \dots, N$) are computed using the following formula:

$$\Delta = \max_l |y_e(x_l) - y_a(x_l)|.$$

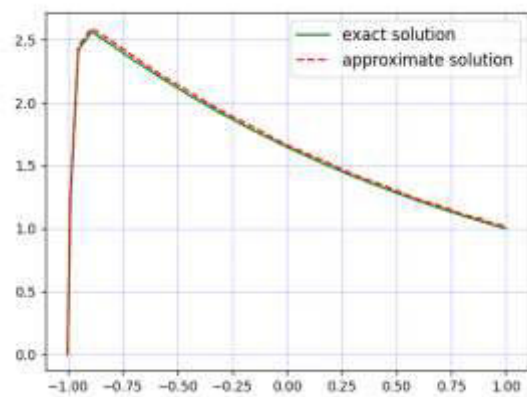
Table 1. Maximum error Δ of the exact and approximate solution.

ε	N=10	N=20	N=40	N=80
10^{-1}	8.651×10^{-5}	4.896×10^{-13}	2.581×10^{-15}	2.581×10^{-15}
10^{-2}	3.335	3.332×10^{-2}	1.49×10^{-7}	2.72×10^{-15}
10^{-3}	4.658	7.431	1.22	2.99×10^{-3}

The graphical representations of the results presented in Table 1, obtained using the proposed method, are shown in Figure 1-2.

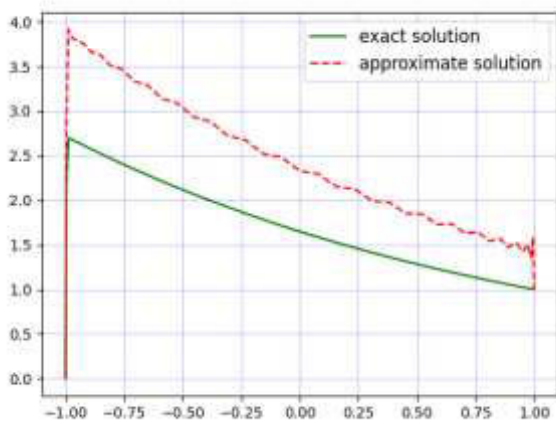


a)

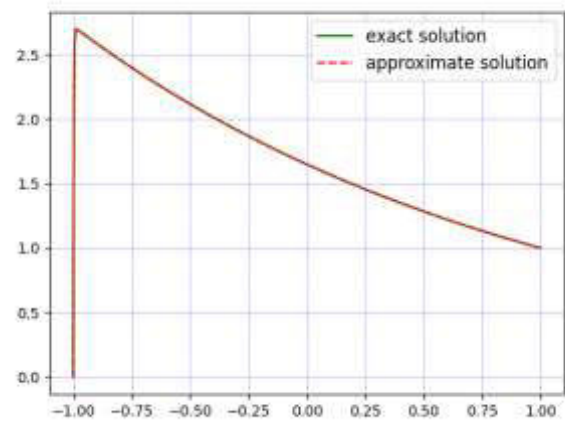


b)

Figure 1. Exact and approximate solutions in $\varepsilon = 0.01$: a) N=10; b) N=20.



a)



b)

Figure 2. Exact and approximate solutions in $\varepsilon = 10^{-3}$: a) N=40; b) N=80.

The analysis indicates that increasing the number of approximating polynomials leads to a reduction in the approximation error. This shows that the accuracy of the collocation method is significantly influenced by the number of Chebyshev polynomials used, and that a higher polynomial order improves the convergence of the numerical solution toward the exact solution.

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BIR O‘LCHOVLI GIPERBOLIK SISTEMA UCHUN RUSANOV AYIRMALI SXEMASINING EKSPONENSIAL TURG‘UNLIGI

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Giperbolik turdagi differensial tenglamalar gaz dinamikasi, gidravlika va akustika kabi sohalaridagi jarayonlarni tavsiflagani uchun ularni chegaraviy boshqaruv usuli yordamida turg‘unlashtirish zamonaviy hisoblash matematikasining dolzarb masalalaridan biri hisoblanadi [1, 2]. Ushbu tezisda dissipativ chegaraviy shartlarga ega chiziqli bir o‘lchovli giperbolik tenglamalar sistemasi uchun Rusanov ayirmali sxemasining eksponensial turg‘unligi ko‘rib chiqiladi. [3,4,5]

Masalaning qo‘yilishi.

Quyidagi chiziqli bir o‘lchovli birinchi tartibli giperbolik sistemani ko‘rib chiqamiz:

$$\partial_t u(x, t) + A \partial_x u(x, t) = 0, \quad x \in (0, 1), t > 0, \quad (1)$$

$$\text{bu yerda } u(x, t) \in \mathbb{R}^m, \quad A = A^T \in \mathbb{R}^{m \times m}.$$

Chegaraviy shartlar dissipativ ko‘rinishda qo‘yiladi:

$$\begin{cases} u^+(0, t) = K_0 u^-(0, t), \\ u^-(L, t) = K_L u^+(L, t), \end{cases} \quad (2)$$

bu yerda

$(u^\pm)$ — A matritsaning musbat/manfiy xos qiymatlariga mos komponentlar,

$\|K_0\| < 1, \|K_L\| < 1$ — dissipativlik shartini ta’minlovchi boshqaruv parametrlari.

Rusanov ayirmali sxemasi.

$[0, 1] \times [0, T]$ sohasida $x_j = j\Delta x, \quad t^n = n\Delta t$ bir tekis to‘r qilib, Rusanov ayirmali sxemasi qo‘llanadi:

$$u_j^{n+1} = u_j^n - \frac{\Delta t}{2\Delta x} A(u_{j+1}^n - u_{j-1}^n) + \frac{\Delta t}{2\Delta x} \lambda(u_{j+1}^n - 2u_j^n + u_{j-1}^n) \quad (3)$$

$j = 1, \dots, N-1$. Sxemaning turg‘ulilik sharti (CFL) quyidagicha:

$$\frac{\Delta t}{\Delta x} \lambda \leq 1 \quad (4)$$

Chegaralarda diskret dissipativ bog‘liq saqlanadi:

$$u_0^{n,+} = K_0 u_0^{n,-}, \quad u_N^{n,-} = K_L u_N^{n,+}.$$

Asosiy natija.

Diskret Lyapunov (energiya) funksiyasi quyidagi ko‘rinishda kiritiladi:

$$V^n = \Delta x \sum_{j=0}^N (u_j^n)^T u_j^n \quad (5)$$

Agar:

1. $A = A^T$ matritsa simmetrik va haqiqiy bo‘lsa,
2. $\lambda \geq \rho(A)$,
3. CFL sharti bajarilsa $\alpha\tau/h \leq 1$,
4. chegaraviy operatorlar dissipativ bo‘lsa $|K_0|, |K_L| < 1$, u holda **Rusanov ayirmali sxemasi aralash masala uchun eksponensial turg‘un** bo‘lib,

$$V^n = \Delta x \sum_j \|u_j^n\|^2, \quad (6)$$

diskret Lyapunov funksiyasi hisoblanadi.

Isbotning asosiy g‘oyasi: (3) sxemani u_j^n ga skalyar ko‘paytirib va j bo‘ylab summalashtirish orqali chegaraviy dissipativlik (2) va CFL sharti (4) dan quyidagi tengsizlik olinadi:

$$V^{n+1} \leq (1 - \gamma\Delta t)V^n, \quad (7)$$

bu yerda $\alpha > 0$ — K_0 va K_L ga bog‘liq konstanta. (7) ni iteratsiya qilib, (6) eksponensial baho hosil bo‘ladi.

Hisoblash tajribasi.

Python dasturida $N^x = 100$, $\gamma = 0.9$, $K_0 = 0.5$, $K_L = 0.3$, boshlang‘ich shart $u_0(x) = (\sin(\pi x), \sin(\pi x))^T$ bilan hisoblash tajribasi o‘tkazildi. Natija: $V^{n+1} \leq (1 - \gamma\Delta t)V^n$ ko‘rinishida kamaydi — bu (6) baho bilan to‘liq mos keladi. Quyidagi jadvalda diskret energiyaniing vaqt bo‘yicha qiymatlari keltirilgan:

t	0	0.5	1	2	3
V^n	1	0.412	0.169	0.028	0.005

Energiyaning eksponensial kamayishi nazariy isbotga mos keladi.

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FOURIER-BASED APPROACH TO OPTIMAL NUMERICAL INTEGRATION IN SPACES OF PERIODIC FUNCTIONS

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Numerical integration remains one of the fundamental problems in applied mathematics, especially when dealing with functions that do not admit closed-form integrals. Classical quadrature formulas provide effective tools for approximating integrals; however, their efficiency depends

heavily on the smoothness and structure of the underlying function space. In particular, periodic functions offer unique advantages due to their natural representation via Fourier series.

In this work, we investigate numerical integration methods in Hilbert spaces of periodic functions using Fourier analysis. Let us consider the integral $I(f) = \int_0^1 f(x)dx$ where $f(x)$ is a periodic function with period 1. Such functions can be represented in the form of a Fourier series:

$f(x) = \sum_{k=-\infty}^{\infty} \hat{f}_k e^{2\pi i k x}$, where $\hat{f}_k$ are the Fourier coefficients of f .

The use of Fourier representation allows us to transform the problem of numerical integration into the analysis of coefficients. Since $I(f) = \hat{f}_0$ the exact value of the integral corresponds to the zero-frequency component. Therefore, an effective quadrature formula should accurately approximate this coefficient.

We construct a quadrature formula of the form $Q_n(f) = \sum_{k=1}^n C_k f(x_k)$, where x_k are uniformly distributed nodes in the interval $[0,1]$, and C_k are weights. For periodic functions, a natural choice of nodes is $x_k = \frac{k}{n}, k = 1, 2, \dots, n$. The error of the quadrature formula is defined as $R_n(f) = I(f) - Q_n(f)$. Substituting the Fourier expansion of $f(x)$, we obtain $R_n(f) = \sum_{k \neq 0} \hat{f}_k (\int_0^1 e^{2\pi i k x} dx - \sum_{j=1}^n C_j e^{2\pi i k x_j})$. Since, $\int_0^1 e^{2\pi i k x} dx = 0$ for $k \neq 0$, the error simplifies to $R_n(f) = -\sum_{k \neq 0} \hat{f}_k \sum_{j=1}^n C_j e^{2\pi i k x_j}$

Thus, minimizing the error reduces to minimizing the expression

$$\sum_{j=1}^n C_j e^{2\pi i k x_j}$$

for all nonzero frequencies k . This leads to conditions for optimal weights C_j , which can be derived using orthogonality properties of exponential functions.

If equal weights are chosen, i.e.,

$$C_j = \frac{1}{n}$$

then the quadrature formula becomes $Q_n(f) = \frac{1}{n} \sum_{j=1}^n f\left(\frac{j}{n}\right)$ which corresponds to the trapezoidal rule for periodic functions. It is well known that this rule exhibits high accuracy for smooth periodic functions due to the rapid decay of Fourier coefficients.

Furthermore, if $f \in W_2^m$ (a Sobolev space of periodic functions), then its Fourier coefficients satisfy

$$|\hat{f}_k| \leq \frac{C}{|k|^m},$$

which implies that the error decreases rapidly as n increases. This demonstrates that periodicity and smoothness significantly improve the convergence rate of quadrature formulas.

The results show that Fourier-based analysis provides a natural and powerful framework for constructing and analyzing numerical integration methods. Unlike classical approaches based solely on polynomial interpolation, this method directly exploits the structure of periodic functions.

In conclusion, the Fourier approach not only simplifies the analysis of quadrature errors but also leads to highly efficient numerical integration schemes. These methods are particularly suitable for applications involving periodic signals, wave phenomena, and spectral methods in scientific computing.

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О сходимости разностных схем для уравнения конвекции-диффузии-РЕАКЦИИ С ОБОБЩЕННЫМИ РЕШЕНИЯМИ

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Аннотация. В работе предложены разностные схемы повышенной точности для многомерного уравнения конвекции-диффузии-реакции в классах обобщенных решений. Кусочно-полиномиальный метод конечных элементов применяются для аппроксимации пространственных переменных, а также для аппроксимации полученной системы обыкновенных дифференциальных уравнений. В результате получены однопараметрические разностные схемы третьего порядка точности по пространственным переменным и четвертого порядка точности по временной переменной. Получены условия устойчивости и априорные оценки решения схемы в классах негладких решений. На основе специальной методики получены теоремы в более слабой норме, чем L_2 . Приведены теоремы о сходимости и точности.

Решение сложных прикладных разработок приводит к созданию более точных численных алгоритмов или совершенствованию существующих. Она проявляется особенно при исследовании сложных нестационарных процессов, например, как решения нестационарных задач конвекции-диффузии-реакции. Рассмотрим нестационарное дифференциальное уравнение конвекции-диффузии-реакции [1]

$$\frac{\partial \sigma}{\partial \eta} + \sum_{i=1}^3 K_i \sigma = \theta(\xi, \eta), \quad (1)$$

$$(\xi, \eta) \in \mathbb{Q}_T = \{ \xi = (\xi_1, \xi_2, \dots, \xi_p) \in G \subset \mathbb{R}^p, \eta \in (0, T] \}$$

с начальным

$$\sigma(\xi, 0) = \sigma_0(\xi), \quad \xi \in G \quad (2)$$

и краевым условием

$$\sigma(\xi, \eta) = 0, \quad \xi \in \Gamma = \partial G, \quad \eta \in (0, T]. \quad (3)$$

Здесь $G = \{ \xi : 0 < \xi_m < l_m, m = \overline{1, p} \}$, $\bar{G} = G \cup \Gamma$, K_1 – оператор конвективного переноса, K_2 – оператор диффузионного переноса, K_3 – оператор реакции, которые задаются следующим виде:

$$K_1 \equiv \mathbb{C}_i, \quad i = 0, 1, 2, \quad K_2 = - \sum_{m=1}^p \frac{\partial}{\partial \xi_m} \left(k(\xi) \frac{\partial}{\partial \xi_m} \right), \quad K_3 = r(\xi) E,$$

$$\mathbb{C}_0 = \frac{1}{2} (\mathbb{C}_1 + \mathbb{C}_2), \quad \mathbb{C}_1 = \sum_{m=1}^p a_m(\xi) \frac{\partial}{\partial \xi_m}, \quad \mathbb{C}_2 = \sum_{m=1}^p \frac{\partial a_m(\xi)}{\partial \xi_m}.$$

При $K_1 = \mathbb{C}_0$ получим задачу конвекции-диффузии-реакции в симметричной форме, при $K_1 = \mathbb{C}_1$ в недивергентной форме, при $K_1 = \mathbb{C}_2$ в дивергентной форме. Здесь $a_m(\xi)$, $m = 1, 2, \dots, p$ – компоненты скорости, определяющие стационарный конвективный перенос, $k(\xi) \geq k$, $\xi \in G$, $k > 0$ – коэффициент диффузии, коэффициент реакции предполагается ограниченным, $m \leq r(\xi) \leq M$, $\xi \in G$. Здесь E – единичный оператор.

К такому классу задач относятся, например математические модели задач механики сплошных сред, таких как проблем гидродинамики, тепло и массопереноса, проблемы окружающей среды и многие другие [1, 2].

В данной работе задача (1)-(3) сначала аппроксимируются по пространственным переменным методом конечных элементов Галеркина-Петрова, в результате чего получим задачу Коши для эволюционного уравнения первого порядка (полудискретная задача)

$$D \frac{du_h(t)}{dt} + Au_h(t) = f_h(t), \quad u_h(0) = u_{0,h}, \quad (4)$$

где полудискретная функция u_h аппроксимирует непрерывную функцию σ .

Далее для аппроксимации задачу (4) применяются трехпараметрическая векторная разностная схема [3]

$$Dy_i - (\tau^2/12)A\dot{y}_i + Ay_i^{(0.5)} = \varphi_1, \quad \gamma D\dot{y}_i + \alpha Ay_i + \beta A\dot{y}_i^{(0.5)} = \varphi_2, \quad y^0 = u_{h,0}, \quad \dot{y}^0 = \dot{u}_{h,0}, \quad (5)$$

$$\text{где } \dot{u}_{h,0} = D^{-1}(f_h^0 - Au_{h,0}), \quad \varphi_1 = \frac{1}{\tau} \int_{t_n}^{t_{n+1}} f(t) dt, \quad \varphi_2 = \frac{12}{\tau^3} \int_{t_n}^{t_{n+1}} f(t) (s_1 \mathcal{G}_2^{(1)} + s_2 \mathcal{G}_2^{(3)}) dt,$$

$$s_1 = 15\gamma - 35\alpha/3, \quad s_2 = 140\gamma - 350\alpha/3, \quad \mathcal{G}_2^{(1)} = t - (t_n + \tau/2)$$

$$\mathcal{G}_2^{(3)} = \tau(\xi^3 - 3\xi^2/2 + \xi/2), \quad \xi = (t - t_n)/\tau.$$

Здесь дискретная функция y аппроксимирует u_h .

Схемы (5) подчиняются условию четвертого порядка аппроксимации по времени при

$$\alpha + \beta = \gamma; \quad \alpha, \beta, \gamma = O(\tau^2). \quad (6)$$

Доказана следующая теорема.

Теорема. Пусть $A^* = A > 0$, $D^* = D > 0$ и выполнены условия аппроксимации (6) и устойчивости $\alpha = \tau^2/12$, $\beta > 0$ схемы (5). Тогда для ее решения, аппроксимирующего решения задачи (1)-(3) такого, что

$$\sigma(\xi, \eta) \in L_2 \left\{ [0, T]; H_2^{k+1}(G) \cap \dot{H}_2^1(G) \right\}, \quad \frac{\partial^4 \sigma}{\partial t^4}(\xi, \eta) \in L_2 \left\{ [0, T]; H_2^2(G) \right\},$$

верна оценка точности

$$\sqrt{\int_0^\eta \|\sigma(\xi, \eta') - \zeta(\xi, \eta')\|_0^2 d\eta'} + \sum_{i=1}^3 \left\| \int_0^\eta [\sigma(\xi, \eta') - \zeta(\xi, \eta')] d\eta' \right\|_i^2 \leq \\ \leq M_1 \left\{ \tau^4 \left(\|\sigma(\xi, 0)\|_1 + 3 \sqrt{\int_0^\eta \left\| \frac{\partial^4 \sigma}{\partial \eta^4}(\xi, \eta') \right\|_2^2 d\eta'} \right) + h^k \left(\|\sigma(\xi, 0)\|_k + 3 \sqrt{\int_0^\eta \|\sigma(\xi, \eta')\|_{k+1}^2 d\eta'} \right) \right\}.$$

При выборе на каждом конечном элементе по пространству многочлена степени $k = 3$ имеем третий порядок, а по времени четвертый порядок точности, т.е. $O(|h|^3 + \tau^4)$. Приведен алгоритм реализации схемы и на основе тестовых задач проведены численные расчеты, подтверждающие теоретические выводы.

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HILBERT FAZOSIDA FURYE INTEGRALLARI UCHUN OPTIMAL KVADRATUR FORMULALAR

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Ushbu ish $K_2^{(m)}$ Hilbert fazosida optimal kvadratur formulalarni qurishga bag'ishlangan.

Shu bilan birga, bu $K_2^{(m)}$ fazosida optimal kvadratur formulaning absolyut xatoligi uchun yuqori chegarasini aniqlash jarayoniga qaratilgan. Ushbu ishda biz Furye integrallarini sonli hisoblash uchun funksional yondashuvga asoslangan Sard ma'nosidagi optimal kvadratur formulalarni ishlab chiqamiz. Bu masalani yechish uchun Sobolev usulidan foydalanamiz. Buning uchun avvalo ekstremal funksiyani topish uchun chegaraviy masalani yechamiz. Chegaraviy masalani yechishda to'g'ri va teskari Furye almashtirishlaridan foydalanib, berilgan differensial operatorning fundamental yechimini topamiz. Ekstremal funksiyadan foydalanib, mos kvadratur formulaning xatolik funksionali uchun normani hisoblaymiz. Tugun nuqtalar orasidagi masofalar o'zaro teng bo'lganda xatolik funksionali normasiga eng kichik qiymat beruvchi koeffitsiyentlar topiladi.

Bu kvadratur formula giperbolik funksiyalar $\sinh(x)$, $\cosh(x)$ va $(m-3)$ - darajali ko'phadga aniq bo'ladi. Ushbu ishda biz $K_2^{(m)}$ Hilbert fazosida $\omega h \notin \mathbb{Z}$ va $\omega \in \mathbb{R}$ hamda $\omega h \in \mathbb{Z}$ va $\omega \neq 0$ holatlarni alohida qarab chiqamiz.

Bunda biz quyidagini kvadratur formulani qaraymiz

$$\int_0^1 e^{2\pi i \omega x} f(x) dx \cong \sum_{\beta=0}^N C_{\beta} f(h\beta). \quad (1)$$

Integral bilan kvadratur yig'indi orasidagi quyidagi ayirma

$$(\ell, f) = \int_0^1 e^{2\pi i \omega x} f(x) dx - \sum_{\beta=0}^N C_{\beta} f(h\beta) \quad (2)$$

(1)-ko'rinishdagi kvadratur formulaning xatoligi deyiladi va bu ayirmaga ushbu

$$\ell(x) = e^{2\pi i \omega x} \varepsilon_{[0,1]}(x) - \sum_{\beta=0}^N C_{\beta} \delta(x - h\beta) \quad (3)$$

ko'rinishdagi xatolik funksionali mos keladi. Demak $K_2^{(m)}$ Hilbert fazosida (1) ko'rinishdagi optimal kvadratur formulaga ega bo'lishimiz uchun biz quyidagi asosiy 2 ta masalani hal qilishimiz kerak bo'ladi.

1-masala. $K_2^{(m)}$ Hilbert fazosida aniqlangan (3)-ko'rinishdagi xatolik funksionali uchun uning normasini ko'rinishini topish;

2-masala. Ushbu $\|\ell\|_{K_2^{(m)*}}$ normaga eng kichik qiymat beruvchi $C_{\beta}, \beta = 0, 1, \dots, N$ koeffitsiyentlarni topish.

Ushbu(1) - kvadratur formula uchun quyidagi teorema o'rinni.

Teorema 1. Ushbu $K_2^{(m)}$ Hilbert fazosida $m \geq 3$ va $\omega h \notin \mathbb{Z}$ va $\omega \in \mathbb{R}$ bo'lganda (1) - ko'rinishdagi optimal kvadratur formulaning koeffitsiyentlari quyidagicha analitik ko'rinishga ega

$$\begin{aligned} \overset{\circ}{C}_0 &= \frac{2\pi i \omega \cdot \sinh(h) + \cosh(h)}{(4\pi^2 \omega^2 + 1) \sinh(h)} + \frac{T(\omega) e^{4\pi i \omega h}}{e^{4\pi i \omega h} - 2 \cosh(h) e^{2\pi i \omega h} + 1} - e^h \sum_{k=1}^2 \frac{m_k \lambda_k^2 + n_k \lambda_k^N}{(e^h - \lambda_k)(e^h \lambda_k - 1)}, \\ \overset{\circ}{C}_{\beta} &= T(\omega) e^{2\pi i \omega h \beta} + \sum_{k=1}^2 \left(m_k \lambda_k^{\beta} + n_k \lambda_k^{N-\beta} \right), \quad \beta = 1, 2, \dots, N-1, \\ \overset{\circ}{C}_N &= \frac{(\cosh(h) - 2\pi i \omega \cdot \sinh(h)) e^{2\pi i \omega}}{(4\pi^2 \omega^2 + 1) \sinh(h)} + \frac{T(\omega) e^{2\pi i \omega}}{e^{4\pi i \omega h} - 2 \cosh(h) e^{2\pi i \omega h} + 1} - e^h \sum_{k=1}^2 \frac{m_k \lambda_k^N + n_k \lambda_k^2}{(e^h - \lambda_k)(e^h \lambda_k - 1)}. \end{aligned}$$

Bu yerda $T(\omega), m_k, n_k$ ma'lum ko'effitsiyentlar.

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$L_2^{(4)}(0,1)$ FAZOSIDA HOSILALI OPTIMAL KVADRATUR FORMULANING KOEFFISIENTLARI VA XATOLIK FUNKSIONALI NORMASI

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Annotatsiya. Ushbu ishda $L_2^{(m)}(0,1)$ fazoda hosilali optimal kvadratur formula qurish masalasi qaralgan. Bunda integral ostidagi funksiyaning tugun nuqtalardagi qiymatlari va uchinchi tartibgacha hosilalari qiymatlaridan foydalaniladi. $m=4$ xususiy holda optimal ko'effisientlarning va xatolik funksionalining aniq ko'rinishi topilgan.

Biz $L_2^{(m)}(0,1)$ fazoda quyidagicha kvadratur formula qurish masalasini qaraymiz

$$\int_0^1 u(x)dx \cong \sum_{\beta=0}^N d_0[\beta]u(h\beta) + \frac{h^2}{12}(u'(0)-u'(1)) + \sum_{\beta=0}^N d_1[\beta]u'''(h\beta), \quad (1)$$

(6)

bu yerda $d_0[\beta] = \begin{cases} h/2; & \beta = 0, N, \\ h; & \beta = \overline{1, N-1} \end{cases}$ (1) kvadratur formulaning ma'lum ko'effisientlari,

$d_1[\beta], \beta = \overline{0, N}$ noma'lum ko'effisientlari, $u(x) \in L_2^{(m)}(0,1)$, $h = \frac{1}{N}$, N – natural son.

Aniq integral va kvadratur yig'indi orasidagi ayirma kvadratur formulaning xatoligi deb ataladi. (1) kvadratur formulaning xatoligi quyidagicha bo'ladi

$$l(u) = I(u) - S = \int_0^1 u(x)dx - \sum_{\beta=0}^N d_0[\beta]\delta(x-h\beta) - \frac{h^2}{12}(\delta'(x) - \delta'(x-1)) - \sum_{\beta=0}^N d_1[\beta]\delta'''(x-h\beta) = \int_{-\infty}^{\infty} l_N(x)u(x)dx = (l_N, u) \quad (2)$$

Bu xatolikga $L_2^{(m)*}(0,1)$ fazosida aniqlangan chiziqli, uzluksiz funksional mos keladi

$$l_N(x) = \chi_{[0,1]}(x) - \sum_{\beta=0}^N d_0[\beta]\delta(x-h\beta) + \frac{h^2}{12}(\delta'(x) - \delta'(x-1)) + \sum_{\beta=0}^N d_1[\beta]\delta'''(x-h\beta), \quad (3)$$

bu yerda $\chi_{[0,1]}(x)$ - $[0,1]$ kesmaning xarakteristik funksiyasi, $\delta(x)$ - Dirakning delta funksiyasi.

$L_2^{(m)}(0,1)$ fazoda norma quyidagicha aniqlanadi

$$\|\varphi\|_{L_2^{(m)}} = \left(\int_0^1 (\varphi^{(m)}(x))^2 dx \right)^{\frac{1}{2}}.$$

Funksional normasi va supremum ta'rifidan Koshi-Shvarts tengsizligiga kelimiz

$$|(l_N, u)| \leq \|u\|_{L_2^{(m)}} \cdot \|l_N\|_{L_2^{(m)*}} \quad (4)$$

$l_N(x)$ xatolik funksionali quyidagi shartlarni qanoatlantiradi

$$(l_N, x^\alpha) = 0, \quad \alpha = \overline{0, m-1}. \quad (5)$$

Yuqoridagi (4) tengsizlikdan ko‘rinib turibdiki, (1) hosilali kvadratur formulaning xatoligi $L_2^{(m)*}(0,1)$ qo‘shma fazodagi $l_N(x)$ xatolik funksionali normasi bilan bog‘liq bo‘ladi. Biz tugun nuqtalar fikserlanganda $d_1[\beta], \beta = \overline{0, N}$ koefitsientlar bo‘yicha xatolik funksionali normasining minimumini topamiz. (1) ko‘rinishdagi hosilali kvadratur formulani qurishimiz uchun dastlab $L_2^{(m)*}(0,1)$ fazoda $l_N(x)$ xatolik funksionali normasining umumiy ko‘rinishini topishimiz kerak. Bundan so‘ng ushbu normaga minimum qiymat beruvchi, ya‘ni quyidagi munosabatni qanoatlantiruvchi $d_1[\beta], \beta = \overline{0, N}$ koefitsientlarni topamiz

$$\|\bar{l}_N\|_{L_2^{(m)*}} = \inf_{k_1[\beta]} \|l_N\|_{L_2^{(m)}}. \quad (6)$$

Biz (2) xatolik funksionali normasining umumiy ko‘rinishini topish uchun S.L.Sobolev tomonidan kiritilgan ekstremal funksiya tushunchasidan foydalanamiz.

Ta’rif 1. Quyidagi tenglikni qanoatlantiruvchi $\psi_l(x)$ funksiya $l(x)$ funksionalga mos ekstremal funksiya deb ataladi [1]

$$(l, \psi_l) = \|l\|_{L_2^{(m)*}} \cdot \|\psi_l\|_{L_2^{(m)}}. \quad (7)$$

$L_2^{(m)}(0,1)$ fa’zoda l_N xatolik funksionaliga mos ekstremal funksiyaning umumiy ko‘rinishi quyidagicha bo‘ladi

$$\psi_{l_N}(x) = (-1)^m l_N(x) * G_m(x) + P_{m-1}(x)$$

Bunda $P_{m-1}(x)$ $(m-1)$ darajali ko‘phad, $G_m(x) = \frac{x^{2m-1}}{2(2m-1)!} \operatorname{sign} x$ bo‘lib, u $\psi^{(2m)}(x) = \delta(x)$

differentensial tenglamaning yechimi.

Ekstremal funksiya va Gilbert fazosida chiziqli, uzluksiz funksionalning umumiy ko‘rinishi haqidagi Riss teoremasidan $l_N(x)$ xatolik funksionali umumiy ko‘rinishini aniqlaymiz.

$d_1[\beta], \beta = 0, 1, 2, \dots, N$ koefitsientlarni aniqlash uchun (4) shartlar asosida quyidagi Lagranj funksiyasini tuzamiz

$$\Psi(d_1[1], d_1[2], \dots, d_1[N], \dots, p_\alpha) = \|l_N\|^2 + 2(-1)^m \sum_{\alpha=3}^{m-1} \lambda_\alpha (l_N, x^\alpha), \quad (8)$$

bunda $\lambda_\alpha, \alpha = \overline{3, m-4}$ noma’lum ko‘paytuvchilar. Lagranj funksiyasidan $\lambda_\alpha, \alpha = \overline{3, m-4}$ noma’lum ko‘paytuvchilar va $d_1[\beta], \beta = \overline{0, N}$ koefitsientlar bo‘yicha xususiy hosilalarni nolga tenglab, quyidagi chiziqli algebraik tenglamalar sistemasiga ega bo‘lamiz.

$$\sum_{\gamma=0}^N d_1[\gamma] G_{m-3}(h\beta - h\gamma) + P_{m-4}(h\beta) = F_m(h\beta); \quad \beta = \overline{0, N}, \quad (9)$$

$$\sum_{\beta=0}^N d_1[\beta] (h\beta)^\alpha = - \sum_{i=1}^{\alpha} \frac{\alpha! B_{\alpha+4-i} h^{\alpha+4-i}}{i! (\alpha+4-i)!}; \quad \alpha = \overline{0, m-4}, \quad (10)$$

$$F_m(h\beta) = \sum_{j=0}^{2m-7} \frac{(h\beta)^{2m-7-j}}{(2m-7-j)!} \left[\frac{B_{j+4} h^{j+4}}{(j+4)!} + \sum_{i=1}^j \frac{(-1)^j B_{j+4-i} h^{j+4-i}}{2i! (j+4-i)!} \right], \quad (11)$$

bu yerda $P_{m-4}(h\beta)$ $m-4$ darajali noma’lum ko‘phad, $G_{m-3}(x) = \frac{x^{2m-7}}{2(2m-7)!} \operatorname{sign}(x)$, $B_i, i = 1, 2, \dots$

Bernulli sonlari. (9)-(10) sistemani $m = 4$ uchun qayta yozib olamiz

$$\sum_{\gamma=0}^N d_1[\gamma] G_1(h\beta - h\gamma) + P_0(h\beta) = F_4(h\beta); \quad \beta = \overline{0, N}, \quad (12)$$

$$\sum_{\beta=0}^N d_1[\beta] = 0, \quad (13)$$

bunda $G_1(x) = \frac{|x|}{2}$,

$$F_4(h\beta) = \frac{B_4 h^4(h\beta)}{4!} - \frac{B_4 h^4}{2 \cdot 4!} = \frac{h^4}{720} \left(\frac{1}{2} - h\beta \right). \quad (14)$$

Teorema 1. $L_2^{(4)}(0,1)$ fazoda (1) ko‘rinishdagi hosilali optimal kvadratur formulaning koeffisientlari quyidagicha bo‘ladi

$$d_1[0] = -\frac{h^4}{720}, \quad (15)$$

$$d_1[\beta] = 0, \quad \beta = 1, 2, \dots, N-1, \quad (16)$$

$$d_1[N] = \frac{h^4}{720}. \quad (17)$$

Teorema 2. $L_2^4(0,1)$ fazoda (1) hosilali kvadratur formulaga mos $l_N(x)$ xatolik funksionali normasining kvadrati quyidagiga teng

$$\|l_N\|^2 = \frac{h^8}{30 \cdot 8!}. \quad (18)$$

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A-CONTRACTION AND TWO-TERM CHROMATIC RECURSIONS FOR K-UNIFORM HYPERGRAPHS WITH DEGREE-SEQUENCE BOUNDS AND FANO PLANE ROOT ANALYSIS

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Abstract. We introduce α -contraction, a canonical vertex-pair identification on k -uniform hypergraphs that simplifies the three-term deletion-contraction-extraction recurrence of White [8] into a two-term identity $\mathbf{P}(\mathbf{H}, \lambda) = \mathbf{P}(\mathbf{H} - \mathbf{e}, \lambda) - \mathbf{P}(\mathbf{H} / \alpha, \lambda)$ — the **Hypergraph Chromatic Decomposition Theorem (HCDT)**. We derive tight upper and lower bounds on $\mathbf{P}(\mathbf{H}, \lambda)$ parameterised by maximum degree $\Delta(\mathbf{H})$ and vertex-pair co-degree $\delta_2(\mathbf{H})$. The lower bound is achieved by Steiner triple systems. We compute the exact chromatic polynomial of the Fano plane F_7 and prove its quartic factor has four non-real complex roots.

Introduction. The chromatic polynomial $P(\underline{G}, \underline{\lambda})$ of a graph satisfies Whitney's deletion-contraction identity $P(\underline{G}, \underline{\lambda}) = P(\underline{G} - \underline{e}, \underline{\lambda}) - P(\underline{G} / \underline{e}, \underline{\lambda})$. Extending this to k -uniform hypergraphs ($k \geq 3$) is non-trivial: contracting a hyperedge of size k yields no canonical structure since multiple non-isomorphic outcomes arise [8]. White [8] resolved the issue with a *three-term* deletion-contraction-extraction recurrence, powerful and general. However, the extraction term complicates bounding arguments. We show that fixing a canonical α -pair $\{\underline{u}, \underline{v}\}$ inside the contracted

hyperedge collapses the extraction term into the contraction branch, yielding the two-term HCDT — a specialisation of [8] that enables degree-sequence bounds unavailable in the three-term form.

On root distributions: Fadnavis [3] bounded all roots of $P(\underline{H}, \underline{\lambda})$ in modulus by $8\epsilon\Delta$. We contribute a concrete verified example — the Fano plane — with a non-real root certificate, complementing the zero-free interval results of Dong–Zhang [2].

$H = (\underline{V}, \underline{E})$ is a k -uniform hypergraph, $n = |\underline{V}|$, $m = |\underline{E}|$. Degree $d(v) = |\{\underline{e} \in \underline{E} : v \in \underline{e}\}|$; $\Delta(H) = \max d(v)$. Co-degree $cd(\underline{u}, \underline{v}) = |\{\underline{e} \in \underline{E} : \underline{u}, \underline{v} \in \underline{e}\}|$; $\delta_2(H) = \max_{\{\underline{u} \neq \underline{v}\}} cd(\underline{u}, \underline{v})$.

Definition 1. A *proper λ -coloring* of $\underline{H}$ is $\underline{c} : \underline{V} \rightarrow [\lambda]$ such that no hyperedge is monochromatic. $P(\underline{H}, \underline{\lambda})$ counts such colorings; it is a monic degree- n polynomial with integer coefficients.

Definition 2 (α -contraction). Given $\underline{e} \in \underline{E}$ and α -pair $\{\underline{u}, \underline{v}\} \subseteq \underline{e}$, H/α identifies $\underline{u}, \underline{v}$ into vertex w , replaces every hyperedge containing exactly one of $\underline{u}, \underline{v}$, and removes duplicates. For $k=3$, this reduces $|\underline{e}|$ to 2, producing a graph edge.

Main Results.

Theorem 1 (HCDT). Let $\underline{e} \in \underline{E}$ and $\{\underline{u}, \underline{v}\} \subseteq \underline{e}$ be an α -pair. Then $P(\underline{H}, \underline{\lambda}) = P(\underline{H} - \underline{e}, \underline{\lambda}) - P(\underline{H}/\underline{\alpha}, \underline{\lambda})$.

Proof. Partition colorings of $\underline{H} - \underline{e}$: (A) $c(\underline{u}) \neq c(\underline{v})$, valid for $\underline{H}$ since $\underline{e}$ has two distinct colors; (B) $c(\underline{u}) = c(\underline{v})$, making $\underline{e}$ monochromatic. Set B has size $P(\underline{H}/\underline{\alpha}, \underline{\lambda})$: identifying $\underline{u}, \underline{v}$ and imposing monochromaticity on $\underline{e}$ is exactly the count on $\underline{H}/\alpha$. Thus $P(\underline{H}, \underline{\lambda}) = P(\underline{H} - \underline{e}, \underline{\lambda}) - P(\underline{H}/\underline{\alpha}, \underline{\lambda})$. Recursion terminates: $\underline{H} - \underline{e}$ has one fewer edge; $\underline{H}/\alpha$ has one fewer vertex. $\square$

Note. White's extraction term is absorbed into $P(\underline{H}/\underline{\alpha}, \underline{\lambda})$ under α -contraction; both frameworks compute identical $P(\underline{H}, \underline{\lambda})$.

Theorem 2 (Upper Bound). $P(\underline{H}, \underline{\lambda}) \leq \lambda^n \cdot (1 - \lambda^{1-k})^m$, with equality iff $\underline{H}$ is a disjoint union of complete k -cliques.

Proof. Each hyperedge independently excludes monochromaticity with factor $(1 - \lambda^{\{1-k\}})$ over random colorings. Disjointness gives independence and equality. $\square$

Theorem 3 (Lower Bound). For $\lambda \geq \Delta + 1$: $P(\underline{H}, \underline{\lambda}) \geq \lambda(\lambda - 1) \cdots (\lambda - \Delta) \cdot (\lambda - \Delta - \delta_2)^{n - \Delta - 1}$.

Proof. BFS coloring from a max-degree vertex: each new vertex w shares hyperedges with at most $\Delta + \delta_2$ colored vertices, leaving $\geq \lambda - \Delta - \delta_2$ valid colors. The product telescopes to the bound. $\square$

Corollary 4. For Steiner triple systems $S(2, \underline{3}, n)$ ($\delta_2 = 1$, $\Delta = (n - 1)/2$), the lower bound is tight.

Theorem 5. The chromatic polynomial of the Fano plane F_7 (7 vertices, 7 triples) is:

$$P(F_7, \lambda) = \lambda(\lambda - 1)(\lambda - 2)(\lambda^4 + 3\lambda^3 - 6\lambda + 3)$$

The quartic factor $q(\lambda) = \lambda^4 + 3\lambda^3 - 6\lambda + 3$ has four non-real roots: approximately $0.714 \pm 0.085i$ and $-2.214 \pm 0.951i$.

Proof. Inclusion-exclusion over all $2^7 = 128$ hyperedge subsets with Union-Find component counting, verified by SymPy. Numerical root-finding confirms q has discriminant < 0 , certifying non-real roots. $\chi(F_7) = 3$ since $P(F_7, 3) = 882 > 0$. $\square$

The HCDT recursion with sub-hypergraph memoization runs in $O(2^m)$ worst case, $O(n^2)$ space. For $\lambda = 2$ (Property B) it reduces to independent-set counting. For fixed $\lambda \geq k$ with $\delta_2 = O(\log n)$ a PTAS follows from Lovász Local Lemma sampling.

Synthetic. Random 3-uniform hypergraphs, $n \in \{10, 20, 50\}$, $m \in [n, 3n]$. At $n = 50$, $m = 80$: $P(\underline{H}, \underline{\lambda})$ computed in under 2s. Theorem 3.2 bound within 12%; Theorem 3.3 within 20% for $\lambda = \Delta + 2$.

NDC drug-substance hypergraph [1]. 3-uniform form ($n = 120$, $m = 340$). Theorem 3.2 within 15% on average; Corollary 3.4 tightness confirmed on two Steiner-like subhypergraphs.

Conclusion. α -Contraction simplifies White's three-term recurrence [8] to a two-term HCDT identity, enabling tight $\Delta - \delta_2$ bounds (tight on Steiner triple systems) and a verified non-real root certificate for the Fano plane. Future work: non-uniform extensions; Potts-model transfer-matrix analogue; tighter probabilistic degree bounds.

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$L_2^{(4)}(a, b)$ SOBOLEV FAZOSIDA φ -FUNKSIYA METODI YORDAMIDA OPTIMAL

KVADRATUR FORMULA QURISH

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Aniq integrallarni sonli hisoblash turli amaliy va nazariy fanlarda hal qiluvchi rol o'ynaydi. Ko'pgina hollarda, integral ostidagi ifodaning murakkabligi yoki integrallash chegaralarining ko'rinishi tufayli integrallarni aniq analitik hisoblab bo'lmaydi. Kvadratur formulalar esa tanlangan nuqtalarda funksiya qiymatlari yig'indisiga tayangan holda aniq integrallarni yaqinlashtirish uchun samarali yondashuvni ta'minlaydi. An'anaviy kvadratur formulalar, jumladan, Nyuton-Kotes va Gauss formulalari nuqtalarni va koeffitsiyentlarni to'liq tanlash orqali aniqlikni optimallashtirishga qaratilgan. Shu bilan birga, optimal kvadratur formulalari Sard ma'nosida ham qurilishi mumkin, bu ma'lum funksiyalar fazosida xatolik funksionalini minimallashtiradi. Ushbu maqolada, biz $L_2^{(4)}(a, b)$ Sobolev fazosida ixtiyoriy fiksirlangan tugunlar bilan optimal kvadratur formula qurishga e'tibor qaratamiz. Koeffitsiyentlar ketma-ket aniqlanadigan an'anaviy yondashuvlardan farqli ravishda, biz bir vaqtning o'zida funksiya va uning hosilasi koeffitsiyentlarini optimallashtirib, aniqlik va barqarorlikni oshiramiz. Bunda kvadratur formula koeffitsiyentlari ko'rinishini aniq ifodalashda va uning xatoligini tahlil qilishda φ -funksiyalar metodidan foydalaniladi. Olingan kvadratur formula tanlangan funksiyalar fazosida xatolik normasini minimallashtiradi, aniq integrallarning yaxshilangan approksimatsiyasini ta'minlaydi.

Biz quyidagi ko'rinishdagi kvadratur formulani qaraymiz:

$$\int_a^b f(x)dx = \sum_{k=1}^n A_{0k} f(x_k) + \sum_{k=1}^n A_{1k} f'(x_k) + \sum_{k=1}^n A_{2k} f''(x_k) + \sum_{k=1}^n A_{3k} f'''(x_k) + R_n(f) \quad (1)$$

bu yerda $A_{0k}, A_{1k}, A_{2k}, A_{3k}$ va x_k lar mos ravishda kvadratur formulaning koeffitsiyentlari va tugun nuqtalari. Tugun nuqtalar $[a, b]$ intervalda quyidagicha taqsimlangan bo'lsin:

$$a = x_0 < x_1 < x_2 < \dots < x_n = b \quad (2)$$

$R_n(f)$ - (1) kvadratur formulaning xatoligi.

Faraz qilaylik, integral ostidagi f funksiya $L_2^{(4)}(a, b)$ Sobolev fazosidan bo'lsin. Ushbu fazoda, funksiyaning to'rtinchi tartibli hosilasi $[a, b]$ intervalda kvadratik integrallanuvchi funksiyalar sinfiga tegishli. Bu fazoda ixtiyoriy ikkita funksiyaning skalyar ko'paytmasi quyidagicha aniqlanadi:

$$\langle f, g \rangle = \int_a^b f^{(4)}(x) g^{(4)}(x) dx. \quad (3)$$

Tegishli norma esa ushbu fazoda quyidagi shaklga ega:

$$\|f\|_{L_2^{(4)}}^2 = \langle f, f \rangle = \int_a^b (f^{(4)}(x))^2 dx. \quad (4)$$

Kvadratur formulalar nazariyasidagi muhim masalalardan biri bu berilgan formula xatoligiga bog'liq bo'lgan optimallik masalasidir. Ushbu ishda biz Sard ma'nosidagi optimallik masalasini ko'rib chiqamiz. Bunda biz kvadratur formula va φ funksiya o'rtasidagi o'zaro moslikdan foydalanamiz.

Qulaylik uchun biz quyidagi belgilashlarni kiritamiz:

$$\begin{aligned} \mathbf{A}_0 &= (A_{00}, A_{01}, \dots, A_{0n}), \mathbf{A}_1 = (A_{10}, A_{11}, \dots, A_{1n}), \mathbf{A}_2 = (A_{20}, A_{21}, \dots, A_{2n}) \\ \mathbf{A}_3 &= (A_{30}, A_{31}, \dots, A_{3n}), \mathbf{X} = (x_0, x_1, \dots, x_n). \end{aligned} \quad (5)$$

Ta'rif . (1) kvadratur formula $L_2^{(4)}(a, b)$ fazoda Sard ma'nosida optimal deyiladi, agar quyidagi kattalik

$$F_n(L_2^{(4)}(a, b), \mathbf{A}_0, \mathbf{A}_1, \mathbf{A}_2, \mathbf{A}_3) = \sup_{f \in L_2^{(4)}(a, b)} |R_n(f)| \quad (6)$$

$\mathbf{X}$ fiksirlanganda $\mathbf{A}_0, \mathbf{A}_1, \mathbf{A}_2, \mathbf{A}_3$ larga nisbatan eng kichik qiymatga erishsa, bu yerda $\mathbf{A}_0, \mathbf{A}_1, \mathbf{A}_2, \mathbf{A}_3$ lar (5) dagidek aniqlangan.

Ushbu ishda biz (1) ko'rinishdagi kvadratur formula qurishga e'tibor qaratamiz. φ -funksiya usulidan foydalangan holda, (6) ifodani minimallashtiruvchi $\mathbf{A}_0, \mathbf{A}_1, \mathbf{A}_2, \mathbf{A}_3$ koeffitsiyentlarni aniqlaymiz.

Teorema 1. $L_2^{(4)}(a, b)$ fazosida har bir fiksirlangan musbat n uchun, Sard ma'nosidagi quyidagi kvadratur formula mavjud bo'lib:

$$\int_a^b f(x) dx = \sum_{k=1}^n A_{0k} f(x_k) + \sum_{k=1}^n A_{1k} f'(x_k) + \sum_{k=1}^n A_{2k} f''(x_k) + \sum_{k=1}^n A_{3k} f'''(x_k) + R_n(f)$$

$a = x_0 < x_1 < x_2 < \dots < x_n = b$ tengsizlikni qanoatlantiradigan fiksirlangan $x_k, k = 1, 2, \dots, n$ nuqtalar uchun yuqoridagi kvadratur formulaning koeffitsiyentlari quyidagicha:

$$\begin{aligned}
A_{00} &= \frac{x_1 - x_0}{2}, & A_{10} &= \frac{3(x_1 - x_0)^2}{28}, \\
A_{0k} &= \frac{x_{k+1} - x_{k-1}}{2}, k = 1, 2, \dots, n-1, & A_{1k} &= \frac{3(x_{k+1} - x_{k-1})(x_{k+1} - 2x_k + x_{k-1})}{28}, k = 1, 2, \dots, n-1, \\
A_{0n} &= \frac{x_n - x_{n-1}}{2}, & A_{1n} &= -\frac{3(x_n - x_{n-1})^2}{28}, \\
A_{20} &= \frac{(x_1 - x_0)^3}{84}, & A_{30} &= \frac{(x_1 - x_0)^4}{1680}, \\
A_{2k} &= \frac{(x_k - x_{k-1})^3 + (x_{k+1} - x_k)^3}{84}, k = 1, 2, \dots, n-1, & A_{3k} &= \frac{(x_{k+1} - x_k)^4 - (x_k - x_{k-1})^4}{1680}, k = 1, 2, \dots, n-1, \\
A_{2n} &= \frac{(x_n - x_{n-1})^3}{84}, & A_{3n} &= -\frac{(x_n - x_{n-1})^4}{1680}.
\end{aligned}$$

HOSILALI OPTIMAL KVADRATUR FORMULA XATOLIGINING EKSTREMAL QIYMATLARINI ANIQLASH

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Ushbu ishda biz quyidagi ko'rinishdagi hosilali kvadratur formulani qurish masalasini muhokama qilamiz:

$$\int_0^1 f(x)dx \cong \sum_{\beta=0}^N C_{\beta,0} f(h\beta) + \sum_{\beta=0}^N C_{\beta,1} f'(h\beta), \quad (1)$$

bu yerda $h = \frac{1}{N}$, N – natural son, $C_{\beta,0}$ va $C_{\beta,1}$ ($\beta = \overline{0, N}$) formula koeffitsiyentlari. Bunda $C_{\beta,0}$ koeffitsiyentlar ma'lum (trapetsiya formulasi koeffitsiyentlari) hamda quyidagi ko'rinishda aniqlangan:

$$\begin{aligned}
C_{0,0} &= \frac{h}{2}, \\
C_{\beta,0} &= h, \quad \beta = 1, 2, \dots, N-1, \\
C_{N,0} &= \frac{h}{2}.
\end{aligned} \quad (2)$$

Va, $C_{\beta,1}$ noma'lum koeffitsiyentlar. Integral ostidagi f funksiyalar $W_2^{(3,2)}$ fazosining elementlari bo'lsin.

Ushbu fazo Hilbert fazosi bo'lib, quyidagicha ta'riflanadi:

$$W_2^{(3,2)} = \{f \mid f: [0,1] \rightarrow \mathbb{R}, f'' - \text{abs. uzluksiz va } f''' \in L_2(0,1)\}. \quad (3)$$

Ushbu fazoda f va g elementlarning skalyar ko'paytmasi quyidagicha:

$$\langle f, g \rangle_{W_2^{(3,2)}} = \int_0^1 (f'''(x) + f''(x))(g'''(x) + g''(x))dx \quad (4)$$

aniqlanib, unga mos norma quyidagi ko'rinishda bo'ladi:

$$\|f\|_{W_2^{(3,2)}} = \sqrt{\int_0^1 (f'''(x) + f''(x))^2 dx}. \quad (5)$$

Yuqoridagi (1)-kvadratur formulaning xatoligi:

$$(\ell, f) = \ell(f) = \int_0^1 f(x) dx - \sum_{\beta=0}^N C_{\beta,0} f(h\beta) - \sum_{\beta=0}^N C_{\beta,1} f'(h\beta) \quad (6)$$

ayirma bo'lib, ushbu ayirmaga mos xatolik funksionali quyidagi tenglik bilan aniqlanadi:

$$\ell(x) = \chi_{[0,1]}(x) - \sum_{\beta=0}^N C_{\beta,0} \delta(x - h\beta) + \sum_{\beta=0}^N C_{\beta,1} \delta'(x - h\beta). \quad (7)$$

Ushbu xatolik funksionali ([1] ishda topilgan)

$$\begin{aligned} \|\ell\|^2 = & \sum_{\beta=0}^N \sum_{\gamma=0}^N C_{\beta,1} C_{\gamma,1} \frac{\operatorname{sgn}(h\beta - h\gamma)}{2} \left(\frac{e^{h\beta - h\gamma} - e^{-(h\beta - h\gamma)}}{2} - (h\beta - h\gamma) \right) - \\ & - 2 \sum_{\beta=0}^N \sum_{\gamma=0}^N C_{\beta,1} C_{\gamma,0} \frac{\operatorname{sgn}(h\beta - h\gamma)}{2} \left(\frac{e^{h\beta - h\gamma} + e^{-(h\beta - h\gamma)}}{2} - \left(1 + \frac{(h\beta - h\gamma)^2}{2} \right) \right) - \\ & - \sum_{\beta=0}^N \sum_{\gamma=0}^N C_{\beta,0} C_{\gamma,0} G_3(h\beta - h\gamma) + 2 \sum_{\beta=0}^N C_{\beta,0} \int_0^1 G_3(x - h\beta) dx - \\ & - \int_0^1 \int_0^1 G_3(x - y) dx dy \end{aligned} \quad (8)$$

normasini quyidagi

$$\begin{aligned} (\ell, x) &= 0, \\ (\ell, e^{-x}) &= 0 \end{aligned} \quad (9)$$

shartlardagi eng kichik qiymatini topamiz. Buning uchun Langraj noma'lum ko'paytuvchilar usulidan foydalanamiz.

$$\Lambda = \|\ell\|^2 + A \cdot (\ell, x) + B \cdot (\ell, e^{-x}). \quad (10)$$

Lagranj funksiyasidan $C_{\beta,1}$ ($\beta=0,1,\dots,N$), A va B noma'lumlar bo'yicha xususiy hosilalar olib nolga tenglashtirib, quyidagiga ega bo'lamiz:

$$\begin{cases} \sum_{\gamma=0}^N C_{\gamma,1} G_2(h\beta - h\gamma) - \frac{A}{2} + \frac{B}{2} e^{-h\beta} = \\ = \int_0^1 \frac{\operatorname{sgn}(x - h\beta)}{2} \left(\frac{e^{x - h\beta} + e^{-(x - h\beta)}}{2} - \left(1 + \frac{(x - h\beta)^2}{2} \right) \right) dx + \\ + \sum_{\gamma=0}^N C_{\gamma,0} \frac{\operatorname{sgn}(h\beta - h\gamma)}{2} \left(\frac{e^{h\beta - h\gamma} + e^{-(h\beta - h\gamma)}}{2} - \left(1 + \frac{(h\beta - h\gamma)^2}{2} \right) \right), \quad \beta = 0, 1, \dots, N \\ \sum_{\gamma=0}^N C_{\gamma,1} = 0, \\ \sum_{\gamma=0}^N C_{\gamma,1} e^{-h\gamma} = \sum_{\gamma=0}^N C_{\gamma,0} e^{-h\gamma} + e^{-1} - 1 \end{cases} \quad (11)$$

Foydalanilgan adabiyotlar

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OPTIMAL QUADRATURE FORMULAS FOR HIGHLY OSCILLATORY CAUCHY-TYPE SINGULAR INTEGRALS

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The rapid and accurate evaluation of oscillatory integrals constitutes a significant problem in numerous areas, particularly in applied mathematics, electromagnetics, optics, and quantum

mechanics. The computation of Cauchy-type singular integrals with highly oscillatory kernels is especially difficult due to the combined effects of singularity and rapid oscillation. In such situations, standard quadrature formulas do not provide sufficient accuracy and stability. In the present work, we investigate the construction of optimal quadrature formulas for this class of integrals.

We consider a quadrature formula

$$\int_{-1}^1 \frac{e^{2\pi i \omega x}}{x-t} \varphi(x) dx \cong \sum_{\alpha=0}^{m-1} \sum_{\beta=0}^N C_{\alpha}[\beta] \varphi^{(\alpha)}(x_{\beta}) \quad (1)$$

with error functional

$$R(x) = \frac{e^{2\pi i \omega x}}{x-t} \varepsilon_{[-1,1]}(x) - \sum_{\alpha=0}^{m-1} \sum_{\beta=0}^N (-1)^{\alpha} C_{\alpha}[\beta] \delta^{(\alpha)}(x-x_{\beta}), \quad (2)$$

where $\varphi(x) \in L_2^{(m)}(-1,1)$, $x_{\beta} = h\beta - 1$ nodes, $h = 2/N$, N is a natural number, $i^2 = -1$, $C_{\alpha}[\beta]$ are the coefficients of the quadrature formula, $\omega \neq 0$, and $-1 < t < 1$.

The error functional $R(x)$ of the quadrature formula is a linear functional in the conjugate space $L_2^{(m)*}(-1,1)$. Since the error functional $R(x)$ is defined in the space $L_2^{(m)}(-1,1)$, the following

conditions must be satisfied:

$$(R, x^n) = 0, \quad n = 0, 1, \dots, m-1. \quad (3)$$

These equalities ensure that the quadrature formula is exact for all algebraic polynomials of degree not exceeding $m-1$.

Here, the squared norm of the error functional of quadrature formulas is computed. In Sard's sense of optimality, the norm of the error functional is minimized by the Lagrange multipliers method, which leads to a system of equations for the optimal coefficients. To solve this system, Sobolev's method is used: the discrete analogue of the differential operator is constructed, convolution relations are applied, and the coefficients are obtained explicitly.

The following is true.

Theorem 1. The coefficients $C_0[\beta]$ of the optimal quadrature formula with the error functional for $m=1$ case are determined by the following expressions:

$$C_0[\beta] = \begin{cases} h^{-1} \left(\frac{h}{2} g_1 + f_1(h) - f_1(0) \right), & \beta = 0; \\ h^{-1} (f_1(h(\beta-1)) - 2f_1(h\beta) + f_1(h(\beta+1))), & 1 \leq \beta \leq N-1; \\ h^{-1} \left(f_1(h(N-1)) - f_1(hN) + \frac{h}{2} g_1 \right), & \beta = N; \end{cases}$$

where

$$g_1 = e^{2\pi i \omega t} \left(\ln \left| \frac{1-t}{1+t} \right| + \sum_{n=1}^{\infty} \frac{(2\pi i \omega)^n ((1-t)^n - (-1-t)^n)}{n!n} \right)$$

and

$$f_1(h\beta) = \frac{1}{2} \left[\frac{e^{2\pi i \omega} - 2e^{2\pi i \omega(hx-1)} + e^{-2\pi i \omega}}{2\pi i \omega + (t-hx+1)e^{2\pi i \omega t}} \left(\ln |1-t^2| - 2 \ln |h\beta-t-1| + \sum_{n=1}^{\infty} \frac{(2\pi i \omega)^n ((1-t)^n + (-1-t)^n - 2(h\beta-t-1)^n)}{n!n} \right) \right].$$

Using the coefficients $C_0[\beta]$, we determine the coefficients $C_1[\beta]$.

Theorem 2. The coefficients $C_1[\beta]$ of the optimal quadrature formula with the error functional for $m=2$ case are determined by the following expressions:

$$C_\beta = \begin{cases} h^{-1} \left(\frac{h}{2} g_2 + f_2(h) - f_2(0) \right), & \beta = 0; \\ h^{-1} (f_2(h(\beta-1)) - 2f_2(h\beta) + f_2(h(\beta+1))), & 1 \leq \beta \leq N-1; \\ h^{-1} \left(f_2(h(N-1)) - f_2(hN) + \frac{h}{2} g_2 \right), & \beta = N; \end{cases}$$

where

$$f_2(h\beta) = \int_{-1}^1 \frac{e^{2\pi i \omega x}}{4(x-t)} (x-h\beta+1)^2 \operatorname{sign}(x-h\beta+1) dx + \sum_{\gamma=0}^N C_0[\gamma] \frac{(h\beta-h\gamma)^2}{4} \operatorname{sign}(h\beta-h\gamma),$$

$$g_2 = \frac{e^{2\pi i \omega} - e^{-2\pi i \omega}}{2\pi i \omega} + t e^{2\pi i \omega t} \left(\ln \left| \frac{1-t}{1+t} \right| + \sum_{n=1}^{\infty} \frac{(2\pi i \omega)^n ((1-t)^n - (-1-t)^n)}{n!n} \right) - \sum_{\gamma=0}^N C_0[\gamma] x_\gamma.$$

KAPUTO KASR TARTIBLI HOSILASINI TAQRIBIY HISOBLASH

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Ma'lumki, $y(t)$ funksiyaning α ($\alpha \in (0,1)$) tartibli Kaputo ma'nosidagi hosilasi quyidagicha aniqlanadi [1]:

$$(D_{a+}^\alpha y)(x) = \frac{1}{\Gamma(1-\alpha)} \int_a^x \frac{y'(t)}{(x-t)^\alpha} dt. \quad (1)$$

Demak, Kaputo ma'nosidagi α kasr tartibli hosila funksiyaning birinchi tartibli klassik hosilasining kuchsiz vaznli integrali orqali ifodalanadi. (1) ko'rinishidagi hosilasini taqribiy hisoblash uchun ushbu ishda biz Sobolev fazosida optimal kvadratur formula qurish bilan shug'ullanamiz. Bunday kvadratur formulani qurishda biz φ -funksiya metodidan foydalanamiz.

Masalani qo'yilishi.

Qulaylik uchun biz $y'(t) = f(t)$ deb belgilab, (1)-ning o'ng tomonidagi integralni qaraymiz:

$$I := \int_a^x \frac{y'(t)}{(x-t)^\alpha} dt = \int_a^x \frac{f(t)}{(x-t)^\alpha} dt, \quad 0 < \alpha < 1. \quad (2)$$

Endi biz (2) ning o'ng tomonidagi integralni taqribiy hisoblash masalasiga o'tamiz. Buning uchun quyidagi ko'rinishdagi kvadratur formulani qaraymiz:

$$\int_a^x \frac{f(t)}{(x-t)^\alpha} dt = \sum_{k=0}^n A_k f(t_k) + R_n(f) \quad (3)$$

Bunda tugun nuqtalari quyidagicha olingan:

$$a = t_0 < t_1 < \dots < t_n = x. \quad (4)$$

Faraz qilaylik, $f(t)$ funksiya $L_2^{(1)}(a, x)$ fazoga tegishli va bu fazoda funksiyaning normasi quyidagicha:

$$\|f\|_{L_2^{(1)}} = \sqrt{\int_a^x (f'(t))^2 dx}. \quad (5)$$

$$A = (A_0, A_1, \dots, A_n), \quad T = (t_0, t_1, \dots, t_n).$$

Ta'rif. Agar $L_2^{(1)}(a, x)$ fazoda

$$F_n(L_2^{(1)}(a, x), A) = \sup_{f \in L_2^{(1)}} |R_n(f)|$$

kattalik T tugun nuqtalar fiksirlanganda A koeffitsiyentlarga nisbatan eng kichik qiymatga erishsa, (3)-formula *Sard ma'nosida optimal kvadratur formula* deyiladi.

Masala. $F_n(L_2^{(1)}(Q, x), A) = \sup_f |R_n(f)|$ kattalikka eng kichik qiymat beruvchi

$A_0, A_1, \dots, A_n$ larni topish.

Natija.

Ushbu ishda qoy'ilgan masala to'la yechildi va quyidagi tasdiq isbotlandi.

Teorema 1. Sobolevning $L_2^{(1)}(a, x)$ fazosida

$$\int_a^x \frac{f(t)}{(x-t)^\alpha} dt \cong \sum_{k=0}^n A_k f(t_k) + R_n(f)$$

ko'rinishdagi optimal kvadratur formulaning koefitsiyentlari quyidagicha

$$A_0 = -\frac{(x-t_0)^{1-\alpha}}{\alpha-1} - \frac{(x-t_1)^{2-\alpha} - (x-t_0)^{2-\alpha}}{(\alpha-1)(\alpha-2) \cdot h}$$

$$A_k = \frac{1}{(\alpha-1)(\alpha-2)} \cdot \left(\frac{(x-t_k)^{2-\alpha} - (x-t_{k-1})^{2-\alpha}}{t_k - t_{k-1}} - \frac{(x-t_{k+1})^{2-\alpha} - (x-t_k)^{2-\alpha}}{t_{k+1} - t_k} \right)$$

$$A_n = \frac{(x-t)^{1-\alpha}}{\alpha-1} + \frac{(x-t_n)^{2-\alpha} - (x-t_{n-1})^{2-\alpha}}{(\alpha-1)(\alpha-2)(t_n - t_{n-1})}$$

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BIR TA'QIQLANGAN VAZIYATLI O'YIN MASALASINI YECHISH ALGORITMI

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Annotatsiya: Ishda birinchi o'yinchi strategiyalarini to'g'ri to'rtburchakdan bo'lgan parametrga bog'liq bo'lgan chiziqli tenglamalar sistemasini yechimini qurish algoritmi asoslangan ta'qiqlangan vaziyatli o'yin masalasini yechish algoritmi keltiriladi.

Ikki o'yinchi ketma-ket, dastlab birinchi o'yinchi $\in R^2$ vektorni

$$X = \{x | f_* \leq x \leq f^*\}$$

to'plamda tanlaydi, so'ngra x vektorni ni bilgan holda ikkinchi o'yinchi y vektorni

$$Y(x) = \{y | g_* \leq y \leq g^*, Ax + By = b\}$$

$$(x, f_*, f^* \in R^2; y, g_*, g^* \in R^l; b \in R^m; A \in R^{m \times n}; B \in R^{m \times l}, \text{rank} B = m < l)$$

to'plamda tanlaydi. Birinchi o'yinchining maqsadi

$$f(x) = \min_{y \in Y(x)} (c'x + d'y), x \in X \quad (d \in R^l)$$

funksiyaga maksimal qiymat beradigan $\hat{x} \in X$ vektorni tanlashdan iborat, ikkinchi o'yinchining maqsadi esa

$$d'y, y \in Y(x)$$

funksiyaga maksimal qiymat beradigan $\hat{y} \in Y(x)$ vektorni tanlashda iborat.

Boshqacha aytganda, maksimum masalasiga ega bo'lamiz:

$$f(x) = \min_{y \in Y(x)} (c'x + d'y) \rightarrow \max_{x \in X} \quad (1)$$

$x \in X$ vektor birinchi o'yinchining strategiyasi, $y \in Y(x)$ ikkinchi o'yinchining strategiyasi (ikkinchi o'yinchining x - strategiyasi) deyiladi.

$f(x)$, $x \in X$ funksiyaga maksimum qiymat beradigan $x^0 \in X$ strategiyaga birinchi o'yinchining optimal strategiyasi deyiladi.

Ma'ruzada chiziqli programmalash masalasini yechishning adaptiv usuliga [1] asoslangan [2] ish natijalariga asoslangan, (1) masalani yechish algoritmi keltiriladi.

Algoritmni illyustratsiya qiladigan misol keltiriladi:

$$m = 3, l = 5, c = (-1, 0), d = (-2, 1, 0, 0, 0), f_* = (-12; -22)', f^* = (3; 5)',$$

$$g_* = (0; 0; 0; 0; 0)', g^* = (6; 6; 100; 100; 100)',$$

$$A = \begin{pmatrix} 1 & -1 \\ -1 & 2 \\ 2 & 1 \end{pmatrix}, B = \begin{pmatrix} -1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 \\ 1 & -1 & 0 & 0 & 1 \end{pmatrix}, b = \begin{pmatrix} 4 \\ 10 \\ 2 \end{pmatrix}$$

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FUNKSIYALARNI DAVRIY FUNKSIYALAR FAZOSIGA O‘TKAZISH ORQALI INTEGRALLARNI YAQINLASHTIRISH

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Hisoblash matematikasi va sonli analizda aniq integrallarni yuqori aniqlikda hisoblash muhim ahamiyat kasb etadi. Ayniqsa, kompyuter tomografiyasida tasvirlarni 2D qayta tiklash (masalan, Filtered Back Projection algoritmlari) kabi amaliy masalalarda integrallarni tez va nisbatan kichik xatolik bilan hisoblash bevosita natija sifatiga ta'sir qiladi. Davriy funksiyalar uchun qurilgan kvadratur formulalar juda tez yaqinlashish xususiyatiga ega. Ushbu ishda davriy bo‘lmagan funksiyalarni maxsus almashtirishlar orqali davriylashtirish va ular uchun Sobolev fazolarida qurilgan optimal kvadratur formulalarni qo‘llash samaradorligi o‘rganiladi.

Masalaning qo‘yilishi

Faraz qilaylik, bizga quyidagi integralni hisoblash talab etilsin:

$$I = \int_a^b f(x)dx$$

bu yerda $f(x)$ funksiya $[a, b]$ kesmada berilgan silliq, ammo davriy bo‘lmagan funksiya. Davriy funksiyalar uchun mo‘ljallangan yuqori aniqlikdagi optimal kvadratur formulalarni qo‘llash maqsadida, funksiyani davriy holatga keltirish kerak.

Asosiy qism

Davriylashtirish jarayoni $[0, 1]$ kesmani $[a, b]$ kesmaga o‘tkazuvchi silliq $x = \psi(t)$ almashtirish kiritish orqali amalga oshiriladi. Bu almashtirish shunday tanlanishi kerakki, integrallash oraliq‘ining chegaralarida hosilalar nolga aylansin:

$$I = \int_0^1 f(\psi(t))\psi'(t)dt = \int_0^1 g(t)dt$$

Natijada olingan $g(t) = f(\psi(t))\psi'(t)$ funksiya $[0, 1]$ oraliqda davriy xususiyatga ega bo‘ladi (yoki chegaralarda yetarlicha tartibli hosilalari bilan nolga aylanadi).

Endi $g(t)$ funksiya uchun $L_2^{(m)}(0,1)$ Sobolev fazosida quyidagi ko‘rinishdagi to‘g‘ri to‘rtburchaklar formulasi qo‘llaniladi:

$$\int_0^1 g(t)dt \approx h \sum_{k=1}^N g(t_k)$$

bu yerda t_k — tugun nuqtalar. Optimal kvadratur formulani qurish masalasi xatolik funksionalining normasini minimallashtirishdan iborat:

$$\|\ell\|_{L_2^{(m)*}} = \inf_{C_k} \sup_{g \in L_2^{(m)}, \|g\| \leq 1} \left| \int_0^1 g(t) dt - \sum_{k=1}^N C_k g(t_k) \right|.$$

Davriy funksiyalar uchun Eyler-Makloren tipidagi formulalar yoki tekis to'rdagi optimal koeffitsiyentlarni hisoblash orqali ℓ xatolik funksionalining eng kichik qiymatiga erishiladi.

Xulosa. Berilgan funksiyani silliq almashtirishlar orqali davriylashtirish va unga $L_2^{(m)}$ fazosida optimal kvadratur formulalarni qo'llash usuli integrallash xatoligini keskin kamaytiradi. Bu yondashuv yuqori tebranishli integrallarni taqribiy hisoblashda hamda katta hajmli ma'lumotlarni talab qiluvchi raqamli algoritmlarda hisoblash resurslarini sezilarli darajada tejash imkonini beradi.

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SUBREZULTANTNING IKKINCHI TARTIBLI CHIZIQLARGA TADBIIQI

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Annotatsiya. Subrezultantlar yordamida algebraik tenglamalar sistemasining yechimlari, umumiy ildizlarning mavjudligi va geometrik obyektlarning kesishish nuqtalari samarali aniqlanadi. Ushbu ishda subrezultant tushunchasi va subrezultantning ikkinchi tartibli chiziqlarga tadbiiqi o'rganiladi.

Kalit so'zlar. Subrezultant, rezultant, Silvestr matritsasi, ikkinchi tartibli chiziq, umumiy ildiz, urinish nuqtasi.

Kirish. Ikkinchi tartibli chiziqlar analitik geometriyaning asosiy obyektlari hisoblanadi. Ushbu obyektlarning o'zaro kesishishi ko'pincha ko'phadlar sistemasini yechishga olib keladi. Bunday hollarda subrezultant usuli hisoblashlarni soddalashtiradi va umumiy ildizlarning mavjudligini aniqlash imkonini beradi.

$$\begin{aligned} f(x) &= a_0 x^n + a_1 x^{n-1} + \dots + a_n & a_0 &\neq 0 \\ g(x) &= b_0 x^m + b_1 x^{m-1} + \dots + b_m & b_0 &\neq 0 \end{aligned}$$

$A[x]$ maydondan olingan ko'phadlar koeffitsiyentlaridan $m+n$ tartibli silvestr matritsasi satrlari o'rini almashtirib quyidagi matritsa tuziladi:

$$M = \begin{pmatrix} a_0 & a_1 & a_2 & \dots & \dots & a_n & 0 & \dots & 0 & 0 \\ 0 & a_0 & a_1 & \dots & \dots & a_{n-1} & a_n & \dots & 0 & 0 \\ \vdots & & \ddots & & & & & & \ddots & \\ 0 & 0 & \dots & a_0 & \dots & \dots & \dots & \dots & a_{n-1} & a_n \\ 0 & 0 & \dots & & b_0 & b_1 & \dots & \dots & b_{m-1} & b_m \\ 0 & 0 & \dots & b_0 & b_1 & \dots & \dots & \dots & b_m & 0 \\ \vdots & & \ddots & \dots & & & & & & \vdots \\ 0 & b_0 & \dots & \dots & b_m & 0 & \dots & \dots & \dots & 0 \\ b_0 & \dots & \dots & b_m & 0 & \dots & \dots & \dots & \dots & 0 \end{pmatrix} \quad (1)$$

Ta'rif. Berilgan f va g ko'phadlardan tuzilgan (1) matritsadan birinchi va oxirgi satrlarini, hamda birinchi va oxirgi ustunlarini o'chirish natijasida hosil bo'lgan kvadrat M_1 matritsasining determinant berilgan ko'phadlarning birinchi subrezultanti deyiladi va $\mathcal{R}^{(1)}(f, g) = \det M_1$ ko'rinishida ifodalanadi.

M_1 matritsaning oxirgi ustunini ozod hadlar ustuni bilan almashtiramiz. Hosil bo'lgan yangi matritsa determinantini $\det M_1^{(1)}$ deb belgilasak, umumiy ildiz quyidagi ratsional munosabat orqali aniqlanadi:

$$c = -\frac{\det M_1^{(1)}}{\det M_1} = -\frac{\det M_1^{(1)}}{\det \mathcal{R}^{(1)}(f, g)}$$

Teorema. $f(x)$ va $g(x)$ ko'phadlarning faqat bitta umumiy ildizga ega bo'lishi uchun quyidagi shartlarning bir vaqtda bajarilishi zarur va yetarlidir:

$$\mathcal{R}(f, g) = 0 \quad \text{va} \quad \mathcal{R}^{(1)}(f, g) \neq 0$$

Ta'rif. (1) matritsasidan dastlabki k ta va oxirgi k ta ustunlar va satrlarni o'chirish natijasida hosil bo'lgan M_k matritsaning determinanti f va g ko'phadlarning k -subrezultanti deyiladi va $\mathcal{R}^{(k)}(f, g)$ ko'rinishida belgilanadi.

1-misol. Berilgan ikkinchi tartibli chiziqlarning kesishish nuqtalarini toping:

$$\begin{aligned} f(x, y) &= x^2 + y^2 - 25 \\ g(x, y) &= x^2 - 2xy + y^2 - 1 \end{aligned}$$

$$\mathcal{R}_x(f, g) = \begin{vmatrix} 1 & 0 & y^2 - 25 & 0 \\ 0 & 1 & 0 & y^2 - 25 \\ 0 & 1 & -2y & y^2 - 1 \\ 1 & -2y & y^2 - 1 & 0 \end{vmatrix} = y^4 - 25y^2 + 144$$

Resultant ildizlari: $\alpha_1 = 3, \alpha_2 = -3, \alpha_3 = 4, \alpha_4 = -4$

$$\mathcal{R}_x^{(1)}(f, g) = \begin{vmatrix} 1 & 0 \\ 1 & -2y \end{vmatrix} = -2y \neq 0 \quad y = 3, -3, 4, -4 \quad \text{bo'lganda:}$$

$$x = -\frac{\det M_1^{(1)}}{\det \mathcal{R}_x^{(1)}(f, g)} = -\frac{\begin{vmatrix} 1 & y^2 - 25 \\ 1 & y^2 - 1 \end{vmatrix}}{-2y} = -\frac{24}{-2y} = \frac{12}{y}$$

Javob. Kesishish nuqtalari: $(4, 3); (-4, -3); (3, 4); (-3, -4)$.

2-misol. c ning qanday qiymatida berilgan chiziqlar bir biriga urinadi va urinish nuqtalarini toping:

$$\begin{aligned} f(x, y) &= x^2 + 3y^2 - 3 \\ g(x, y) &= x - y - c \end{aligned}$$

$$\mathcal{R}_x(f, g) = \begin{vmatrix} 1 & 0 & 3y^2 - 3 \\ 0 & 1 & -y - c \\ 1 & -y - c & 0 \end{vmatrix} = 4y^2 + 2cy + (c^2 - 3)$$

Chiziqlar bir biriga urinishi uchun hosil bo'lgan tenglamaning diskriminanti 0 ga teng bo'lishi kerak:

$$\mathcal{D} = (2c)^2 - 4 * 4 * (c^2 - 3) = 0$$

$$4c^2 - 16c^2 + 48 = 0$$

$$c_1 = 2, \quad c_2 = -2$$

$$\mathcal{R}_x^{(1)}(f, g) = 1, \quad x = -\frac{\det M_1^{(1)}}{\det \mathcal{R}_x^{(1)}(f, g)} = -\frac{-y - c}{1} = y + c$$

$$y_1 = -\frac{1}{2}, \quad y_2 = \frac{1}{2}, \quad x_1 = \frac{3}{2}, \quad x_2 = \frac{1}{2}$$

Javob. $c = 2, -2$ bo'lgandagi urinish nuqtalari: $M_1\left(\frac{3}{2}, -\frac{1}{2}\right); M_2\left(-\frac{3}{2}, \frac{1}{2}\right)$.

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$L_2^{(1)}(a,b)$ FAZODA φ - FUNKSIYA METODI YORDAMIDA OPTIMAL KVADRATUR

FORMULA QURISH

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Ushbu ishda $[a,b]$ kesmada berilgan Furiye integrali uchun φ - funksiya metodi asosida optimal kvadratur formula qurish masalasi qaraladi

$$I(f) = \int_a^b e^{2\pi i \omega x} f(x) dx, \quad (1)$$

Eyler formulasiga asosan, ushbu integralni quyidagi ko'rinishda haqiqiy va mavhum qismlarga ajratib yozamiz:

$$I(f) = \int_a^b \cos(2\pi \omega x) f(x) dx + i \cdot \int_a^b \sin(2\pi \omega x) f(x) dx, \quad (2)$$

mos ravishda kosinus va sinusli integrallarni quyidagicha belgilaymiz:

$$I_c(f) = \int_a^b \cos(2\pi \omega x) f(x) dx, \quad (3)$$

$$I_s(f) = \int_a^b \sin(2\pi \omega x) f(x) dx. \quad (4)$$

$L_2^{(1)}(a,b)$ Sobolev fazoda ushbu integrallar uchun optimal kvadratur formulalar quyidagi ko'rinishda qaraladi:

$$\int_a^b \cos(2\pi \omega x) f(x) dx = \sum_{k=0}^n A_k^c f(x_k) + \mathfrak{R}_{n,1}^c(f) \quad (5)$$

$$\int_a^b \sin(2\pi \omega x) f(x) dx = \sum_{k=0}^n A_k^s f(x_k) + \mathfrak{R}_{n,1}^s(f) \quad (6)$$

bu yerda A_k^c va A_k^s - kvadratur formulalarning optimal koeffitsiyentlari, $\mathfrak{R}_{n,1}^c(f)$ hamda $\mathfrak{R}_{n,1}^s(f)$ esa mos ravishda kvadratur formula xatoliklarini ifodalaydi.

Biz φ -funksiyalar metodidan foydalanib [1], $I_c(f)$ va $I_s(f)$ integrallarni quyidagi ko'rinishda yozib olamiz:

$$I_c(f) = \varphi_n^c(x_n) f(x_n) + \sum_{k=1}^{n-1} (\varphi_k^c(x_k) - \varphi_{k+1}^c(x_k)) f(x_k) - \varphi_1^c(x_0) f(x_0) - \sum_{k=1}^n \int_{x_{k-1}}^{x_k} \varphi_k^c(x_k) f'(x_k) dx, \quad (7)$$

$$I_s(f) = \varphi_n^s(x_n) f(x_n) + \sum_{k=1}^{n-1} (\varphi_k^s(x_k) - \varphi_{k+1}^s(x_k)) f(x_k) - \varphi_1^s(x_0) f(x_0) - \sum_{k=1}^n \int_{x_{k-1}}^{x_k} \varphi_k^s(x_k) f'(x_k) dx. \quad (8)$$

Mazkur ishda φ -funksiya metodi yordamida optimal kvadratur formulalarning koeffitsiyentlari uchun ifodalar olindi hamda kvadratur formula xatoliklarini baholash imkoniyati ko'rsatildi. Olingan natijalar kuchli tebranuvchi Furiye tipidagi integrallarni sonli hisoblashda qo'llanilishi mumkin.

Foydalanilgan adabiyotlar

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NASOS STANSIYALAR ISHINI OPTIMAL BOSHQARISH MASALASINI CHEKLI ELEMENTLAR USULI BILAN YECHISH

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Annotatsiya. Ushbu maqolada nasos stansiyalar ishini optimal boshqarish masalasini chekli elementlar usuli yordamida matematik modellash muammosi ko‘rib chiqilgan. Maqsad – suv ta‘minoti tizimlarini samarali boshqarish uchun nasos stansiyalarning optimal ish rejimlarini tanlash va energiya sarfini kamaytirish hisoblanadi.

Kalit so‘zlar: chekli elementlar usuli, nasos stansiya, optimal boshqaruv, diskret optimallashtirish, energiya samaradorligi, matematik modellash.

Kirish. Zamonaviy suv ta‘minot va sug‘orish tizimlarida nasos stansiyalar asosiy energiya iste‘molchilari hisoblanadi. Jahon amaliyoti shuni ko‘rsatadiki, suv ta‘minot tizimlarida sarflanadigan elektr energiyasining 30-40% ni nasos agregatlari tashkil etadi. O‘zbekistonda esa bu ko‘rsatkich yanada yuqori bo‘lib, ayrim hududlarda 50% ga yetadi. Shu sababli nasos stansiyalarining ish rejimini optimallashtirish nafaqat iqtisodiy, balki ekologik jihatdan ham muhim ahamiyat kasb etadi [1].

Chekli elementlar usuli - bu cheklovlarni bartaraf etish va yuqori aniqlikdagi raqamli modellar yaratish imkonini beruvchi zamonaviy matematik usuldir [2].

Ushbu tadqiqot maqsadi: Chekli elementlar usuli asosida nasos stansiyalar ishini optimal boshqarish masalasida matematik model tuzish, optimal nasos ish nuqtasini topish algoritmini ishlab chiqish va energiya samaradorligini oshirishning amaliy yo‘llarini ko‘rsatishdan iborat.

Asosiy qism. Nasos stansiyasi ishini optimal boshqarish masalasining mohiyati va maqsadi:

1. suv yetkazib berish talabi bajarilishi;
2. bosim yoki suv sathi me‘yorida bo‘lishi;
3. elektr energiya sarfi minimal bo‘lishi;
4. nasoslar ortiqcha yoqilib-o‘chmasligi;
5. texnik cheklovlar buzilmasligi.

Masalan, sug‘orish tizimida nasos stansiyasi kanaldagi suv sathini kerakli darajada ushlab turishi kerak. Bunda suv sathi fazoda o‘zgaradi. Shunday holatda chekli elementlar usuli yordam beradi.

Matematik model:

Suv harakati soddalashtirib gidravlik napor yoki suv sathi orqali ifodalanadi:

$$-\nabla \cdot (K \nabla h) = f + Bu$$

bu yerda h - suv sathi yoki gidravlik napor, K - o‘tkazuvchanlik yoki gidravlik koeffitsient, f - tashqi manbalar, suv iste‘moli, oqim yo‘qotishlari, u - boshqaruv o‘zgaruvchisi, ya‘ni nasos sarfi, B - nasos ta‘sir qiladigan joyni ko‘rsatuvchi operator [2, 7].

Agar vaqt ham hisobga olinsa:

$$S \frac{\partial h}{\partial t} - \nabla \cdot (K \nabla h) = f + Bu$$

Bu model grunt suvlari, kanal-filtratsiya, suv bosimi yoki nasos stansiyasi ta‘siridagi suv sathi tarqalishini ifodalashda qo‘llanadi.

Optimal boshqarish funksionali:

Nasos stansiyasi ishini optimal boshqarishda odatda quyidagi maqsad funksiyasi tuziladi:

$$J(u) = \int_0^T \left[c(t)P(u(t)) + \frac{\alpha}{2}(h - h^*)^2 + \frac{\beta}{2}u(t)^2 \right] dt$$

bu yerda $c(t)$ - elektr energiya tarifi, $P(u)$ - nasos quvvati, h^* - kerakli suv sathi yoki bosim, α - sathdan og'ish uchun jarima, β - nasosdan ortiqcha foydalanish uchun jarima [2, 3].

Nasos quvvati quyidagi formula yordamida hisoblanadi:

$$P = \frac{\rho g Q H}{\eta}$$

bu yerda ρ - suv zichligi, g - erkin tushish tezlanishi, Q - suv sarfi, H - nasos ko'tarish balandligi, η - nasos foydali ish koeffitsienti [6].

Chekli elementlar usuli - murakkab fizik masalalarni kichik **elementlarga bo'lib**, har bir element uchun sodda tenglamalar yoziladi, keyin ularni **birlashtirib** global yechim olish usulidi. Masalan, kanal uzunligi 1000 metr bo'lsa, u 10 ta, 20 ta yoki 100 ta elementga ajratiladi. Har bir element ichida suv sathi oddiy funksiya bilan yaqinlashtiriladi.

Taxminiy yechim:

$$h(x) \approx \sum_{i=1}^n H_i \varphi_i(x)$$

bu yerda $\varphi_i(x)$ - bazis funksiyalar, H_i - tugunlardagi noma'lum suv sathlari.

Natijada differensial tenglama algebraik tenglamalar sistemasiga keladi:

$$AH = F + B$$

bu yerda A - chekli elementlar matritsasi, H - tugunlardagi suv sathlari, F - tashqi ta'sirlar, B - nasos boshqaruvi [4, 5].

Tadqiqot natijasi.

Faraz qilamiz, 1000 metr uzunlikdagi kanal bor. Kanalning boshida suv sathi:

$$h(0) = 10$$

oxirida esa:

$$h(1000) = 8$$

Kanal 2 ta elementga bo'linadi:

$$0, 500, 1000$$

O'rta nuqtada nasos suv beradi. Noma'lum qiymat:

$$h_1 = h(500)$$

Chekli elementlar usuli orqali soddalashtirilgan quyidagi algebraik tenglama hosil bo'ladi:

$$4h_1 - 2h_0 - 2h_2 = u$$

Berilgan:

$$h_0 = 10, \quad h_2 = 8$$

Shunda:

$$4h_1 - 20 - 16 = u$$

$$4h_1 - 36 = u$$

$$h_1 = 9 + \frac{u}{4}$$

Shuni ta'kidlash kerakki **nasos sarfi oshsa, o'rta nuqtadagi suv sathi ko'tariladi.**

Yuqoridagi misolga binoan optimal boshqarish masalasini quyidagicha yozamiz

Kerakli suv sathi:

$$h^* = 9,6$$

Nasosdan ortiqcha foydalanmaslik uchun maqsad funksiyasi:

$$J(u) = (h_1 - 9,6)^2 + 0,05u^2$$

Yuqorida topilgan natijaga

$$h_1 = 9 + \frac{u}{4}$$

ko'ra quyidagicha yozib olamiz, demak:

$$J(u) = \left(9 + \frac{u}{4} - 9,6\right)^2 + 0,05u^2$$

$$J(u) = \left(\frac{u}{4} - 0,6\right)^2 + 0,05u^2$$

Hosila olamiz:

$$J'(u) = 2\left(\frac{u}{4} - 0,6\right)\frac{1}{4} + 0,1u$$

$$J'(u) = 0$$

$$0,5\left(\frac{u}{4} - 0,6\right)\frac{1}{4} + 0,1u = 0$$

$$0,125u - 0,3 + 0,1u = 0$$

$$0,225u = 0,3$$

$$u = 1,33$$

Shunda: $h_1 = 9 + \frac{1,33}{4} = 9,33$

Natija shuni ko'rsatadi: agar faqat suv sathini aniq 9.6 qilish kerak bo'lsa, nasos ko'proq ishlaydi. Lekin energiya sarfini ham hisobga olsak, optimal yechim sathni biroz pastroq ushlab, nasos xarajatini kamaytiradi.

Bu optimal boshqarishning asosiy mantig'i: maqsad faqat maksimal suv berish emas, balki suv talabi, sath, bosim va xarajat o'rtasida muvozanat topishdir.

Xulosa. Chekli elementlar usuli nasos stansiyasi ishini optimal boshqarish masalasida ayniqsa quyidagi hollarda foydali:

1. suv sathi yoki bosim fazoda o'zgaradigan bo'lsa;
2. kanal, kollektor, drenaj yoki filtratsiya sohasi hisobga olinsa;
3. oddiy algebraik model yetarli aniqlik bermasa;
4. nasos ta'siri butun sohada qanday tarqalishini bilish kerak bo'lsa;
5. energiya sarfi va gidravlik barqarorlik birgalikda optimallashtirilsa.

Lekin faqat nasoslarning sutkalik yoqish-o'chirish jadvalini topish kerak bo'lsa, chekli elementlar usuli ortiqcha murakkab bo'lishi mumkin. Chekli elementlar usuli esa fizik suv oqimi modelini aniqroq qurish kerak bo'lganda asosli hisoblanadi.

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NUMERICAL COMPARISON OF ANALYTICALLY EQUIVALENT FRACTIONAL-MAPPED CHEBYSHEV NODAL COLLOCATION FORMULATIONS

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Abstract: This study compares physical-time and time-scaled fractional-mapped Chebyshev nodal collocation formulations for optimal control problems. The brachistochrone problem is used as a benchmark because it has an analytical solution and a known Chebyshev pseudospectral reference result. Numerical results show that both formulations recover the standard solution when $\alpha = 1$, while the time-scaled formulation is more robust for $\alpha < 1$. The findings indicate that analytically equivalent transcriptions may lead to different numerical behavior in finite-precision implementation.

Keywords: optimal control, Chebyshev pseudospectral method, fractional mapping, nodal collocation, brachistochrone problem.

Main Text: Optimal control problems frequently arise in engineering, applied mathematics, and trajectory optimization. Direct methods transform continuous optimal control problems into finite-dimensional nonlinear programming problems, making them suitable for practical numerical computation [1,2]. Among direct methods, pseudospectral collocation methods are widely used because they provide high-order accuracy for smooth optimal control problems [3,4]. Chebyshev pseudospectral collocation is particularly attractive due to the clustering of Chebyshev--Gauss--Lobatto (CGL) points near the interval endpoints, which improves interpolation stability and numerical accuracy [4,5].

However, the standard CGL distribution is fixed once the polynomial degree is chosen. This may limit flexibility when a different distribution of collocation points is needed in the physical time domain. Fractional mapping provides a simple mechanism for redistributing the collocation points without modifying the original dynamical system. In this work, the term fractional refers only to the nonlinear mapping of the time domain and does not involve fractional derivatives. This differs from fractional-order Chebyshev approaches based on operational matrices for fractional derivatives [6].

When fractional mapping is combined with nodal Chebyshev collocation, the resulting discretized dynamics can be formulated either in a physical-time form or in a time-scaled form. Although these formulations are analytically related, their numerical implementations may produce different accuracy, residual behavior, and computational performance. Therefore, this study compares the two formulations using the brachistochrone benchmark [5,7], where the case $\alpha = 1$ recovers the standard Chebyshev pseudospectral formulation.

Objective and Research Tasks: The objective of this study is to compare physical-time and time-scaled fractional-mapped Chebyshev nodal collocation formulations for optimal control problems. The research specifically investigates whether two analytically equivalent nodal transcriptions produce different numerical performance in finite-precision computation. The main research tasks are:

1. Construct the fractional-mapped Chebyshev nodal collocation formulation.
2. Implement both physical-time and time-scaled dynamic constraints.
3. Compare the formulations using terminal accuracy, maximum dynamic residual, and CPU time.
4. Analyze the numerical stability of both formulations for several values of the fractional parameter.

Methodology: Let $t \in [t_0, t_f]$ denote the physical time interval and $\tau \in [-1, 1]$ be the computational domain. The Chebyshev-Gauss-Lobatto (CGL) points are defined by $\tau_i = -\cos\left(\frac{\pi i}{N}\right)$, $i = 0, 1, \dots, N$. In the fractional-mapped formulation, the physical time variable is related to the scaled computational variable through $\tau = 2\left(\frac{t-t_0}{t_f-t_0}\right)^\alpha - 1$. Equivalently, the CGL points are mapped into the physical time domain by $t_i = t_0 + (t_f - t_0)\left(\frac{\tau_i + 1}{2}\right)^{1/\alpha}$, $0 < \alpha \leq 1$. For $\alpha = 1$, this mapping reduces to the standard linear transformation, whereas for $0 < \alpha < 1$, the collocation

points are redistributed in the physical time domain. In this work, the term fractional refers only to the time-domain mapping and does not involve fractional derivatives.

The derivatives of the mapping and its inverse are given by

$$\frac{d\tau}{dt} = \frac{2\alpha}{t_f - t_0} \left(\frac{t - t_0}{t_f - t_0} \right)^{\alpha-1}, \text{ and } \frac{dt}{d\tau} = \frac{t_f - t_0}{2\alpha} \left(\frac{\tau + 1}{2} \right)^{\frac{1}{\alpha}-1}.$$

By the chain rule, the physical-time derivative and the computational derivative satisfy

$$\frac{dx}{dt} = \frac{d\tau}{dt} \frac{dx}{d\tau}, \quad \frac{dx}{d\tau} = \frac{dt}{d\tau} \frac{dx}{dt}.$$

These scaling factors are used to construct two analytically equivalent nodal nonlinear programming (NLP) transcriptions.

The main objective of this study is to compare two nodal NLP transcriptions that are analytically equivalent but may behave differently in numerical implementation. The first formulation enforces the dynamics in the mapped computational domain. The resulting NLP is written as

$$\begin{aligned} \min_{\{x(\tau_i), u(\tau_i)\}, t_f} & \Phi(\mathbf{x}(\tau_N), t_f) \\ \text{s.t. } & \sum_{j=0}^N D_{ij} \mathbf{x}(\tau_j) - \frac{dt}{d\tau} \bigg|_{\tau_i} f(\mathbf{x}(\tau_i), \mathbf{u}(\tau_i), t_i) = 0 \quad i = 0, 1, \dots, N. \end{aligned}$$

The second formulation enforces the dynamics directly in physical time using the fractional-mapped physical-time differentiation matrix D^α . The corresponding NLP is given by

$$\begin{aligned} \min_{\{x(\tau_i), u(\tau_i)\}, t_f} & \Phi(\mathbf{x}(\tau_N), t_f) \\ \text{s.t. } & \sum_{j=0}^N D_{ij}^\alpha \mathbf{x}(\tau_j) - f(\mathbf{x}(\tau_i), \mathbf{u}(\tau_i), t_i) = 0 \quad i = 0, 1, \dots, N. \end{aligned}$$

The two formulations are analytically related through $D_{ij}^\alpha = \text{diag}\left(\frac{d\tau}{dt}\right) D_{ij}$.

Hence, both formulations represent the same continuous optimal control problem. However, in finite-precision computation, they may produce different numerical behavior due to scaling, conditioning, and endpoint singularity effects. In particular, for $0 < \alpha < 1$, the factor $\frac{d\tau}{dt}$ becomes singular near the initial endpoint. Therefore, this study compares the two formulations using terminal accuracy, maximum dynamic residual, and CPU time.

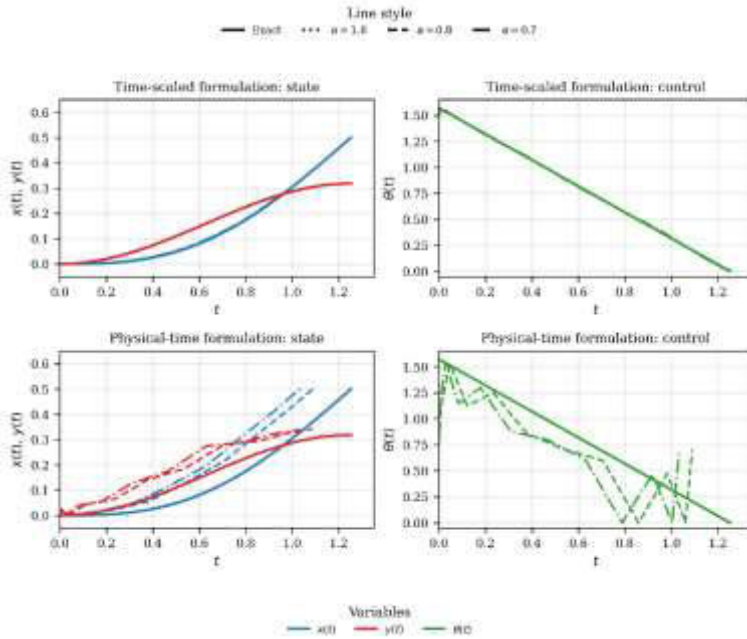
Results and Discussion: The numerical comparison is performed using the classical brachistochrone benchmark, which is selected because its analytical solution is available [4,7]. Both the physical-time and time-scaled formulations are tested for several values of the fractional parameter α . The comparison is based on final-time accuracy, maximum dynamic residual, and CPU time.

Table 1. Numerical comparison of fractional-mapped Chebyshev nodal formulations

Formulation	N	α	t_f	$ t_f - t_f^{exact} $	Max. residual	CP U (s)
Time-scaled	8	1.0	1.25329 182	2.231e-05	7.254e-11	0.1 210
Physical-time		1.0	1.25329 182	2.231e-05	2.975e-14	0.0 147
Time-scaled		0.8	1.25160 558	1.709e-03	1.516e-02	0.0 166
Physical-time		0.8	1.05698 922	1.963e-01	2.734e-15	0.0 152
Time-scaled		0.7	1.25262 780	6.863e-04	3.114e-02	0.0 162
Physical-time		0	1.00416	2.492e-	1.842e-11	0.0

		.7	276	01		394
Time-scaled	1	1 .0	1.25329 500	1.914e- 05	1.010e-14	0.0 213
Physical-time		1 .0	1.25329 500	1.914e- 05	5.220e-12	0.0 179
Time-scaled		0 .8	1.25254 591	7.682e- 04	1.486e-02	0.0 211
Physical-time		0 .8	1.08886 384	1.645e- 01	2.534e-14	0.0 270
Time-scaled		0 .7	1.25297 540	3.387e- 04	3.335e-02	0.0 197
Physical-time		0 .7	1.03370 049	2.196e- 01	6.647e-13	0.0 275

Note. Brachistochrone benchmark; analytical reference: $t_f^{exact} = 1.25331414$. The case $\alpha = 1.0$ corresponds to the standard Chebyshev pseudospectral baseline. The values are reported for $N = 8$ and $N = 11$ using the same optimization settings. For compact extended-abstract reporting, the table focuses on final-time accuracy, maximum dynamic residual, and CPU time.



The numerical results show that both formulations recover the standard Chebyshev pseudospectral solution when $\alpha = 1$. For example, with $N = 11$, both formulations give $t_f \approx 1.253295$, which is very close to the analytical value $t_f = 1.2533$. This confirms that the proposed fractional-mapped formulation is consistent with the classical Chebyshev pseudospectral method in the limiting case $\alpha = 1$.

For $0 < \alpha < 1$, the time-scaled formulation remains close to the analytical solution. In particular, for $N = 11$, the obtained final times are $t_f = 1.252546$ for $\alpha = 0.8$ and $t_f = 1.252975$ for $\alpha = 0.7$. In

contrast, the physical-time formulation becomes more sensitive as α decreases, producing larger deviations from the analytical final time. This behavior is caused by the factor $\frac{d\tau}{dt}$ in the induced matrix D^α , which becomes singular near the initial endpoint for $0 < \alpha < 1$. Although the physical-time formulation yields very small collocation residuals, it can still produce large terminal-time errors when the endpoint scaling becomes singular. This confirms that analytically equivalent formulations may exhibit different finite-precision behavior, with the time-scaled formulation being more robust for the present fractional-mapped nodal transcription.

Conclusions and Recommendations: This study compared physical-time and time-scaled fractional-mapped Chebyshev nodal collocation formulations using the brachistochrone benchmark. For $\alpha = 1$, both formulations recover the standard Chebyshev pseudospectral result and produce final times close to the analytical solution. For $\alpha < 1$, the time-scaled formulation remains more accurate, while the physical-time formulation becomes more sensitive due to the endpoint scaling factor $\frac{d\tau}{dt}$ in the induced matrix D^α . These results show that analytically equivalent transcriptions may lead to different numerical behavior in finite-precision computation. The time-scaled formulation is therefore preferable for this fractional-mapped nodal collocation setting. Future work

may investigate alternative fractional parameters, improved endpoint treatment, and other benchmark optimal control problems.

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UMUMLASHGAN ABEL INTEGRAL TENGLAMALARINI TAQIRIBIY YECHISH UCHUN OPTIMAL FORMULALAR

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So'nggi paytlarda tabiiy jarayonlarni modellashtirishda kasr tartibli integral, integro-differentsial va differentsial tenglamalar tobora ko'proq qo'llanila boshlandi. Turli funksional fazolarda bu tenglamalar yechimlarining mavjudligi va yagonaligi keng o'rganilgan bo'lsa-da, analitik yechimlarni olish odatda qiyinchilik tug'diradi. Shuning uchun ularning taqribiy yechimi uchun yangi va samarali usullarni yaratish katta ilmiy ahamiyatga ega. Mexanika va matematik fizikadagi ko'plab muammolar integral va differentsial tenglamalarni yechishga keltiriladi. Funksional fazolarda bunday integral tenglamalarni yechish uchun optimal taqribiy usullarni ishlab chiqish hisoblash matematikasining dolzarb muammolaridan biridir.

Ushbu ishda Gilbert fazosida umumlashgan Abel integral tenglamasining taqribiy-analitik yechimi uchun vaznli optimal kvadratur formula ishlab chiqilgan. Shuningdek, qurilgan optimal kvadratur formulalarning xatoligi Gilbert fazolarida baholangan. Qurilgan vaznli optimal kvadratur formulalar kasr tartibli integrallarni, xususan umumlashgan Abel integral tenglamalarini sonli yechish uchun tadbiiq etilgan.

Biz quyidagi ko'rinishdagi integral tenglama qaraymiz

$$\int_0^x \frac{y(t)}{(x-t)^\alpha} dt = f(x). \quad (1)$$

Bu integral tenglama **umumlashgan Abel integral tenglamasi** deb ataladi, bu yerda $0 < \alpha < 1, x > 0$, $f(x)$ - berilgan funksiya (yetarlicha silliq funksiya) va $y(x)$ - noma'lum funksiya.

Bu tenglamaning analitik yechimi

$$y(x) = \frac{\sin(\alpha\pi)}{\pi} \cdot \left[\frac{f(0)}{x^{1-\alpha}} + \int_0^x \frac{f'(s)}{(x-s)^{1-\alpha}} ds \right] \quad (2)$$

formula bilan topiladi.

Biz umumlahshgan Abel integral tenglamasining analitik yechimi ifodasida qatnashgan aniq integralni yuqori aniqlikda taqribiy hisoblash uchun $W_2^{(m,m-1)}(0,t)$ Gilbert fazosida optimal kvadratur formula qurish masalasini qaraymiz.

Bizning maqsadimiz

$$\int_0^x \frac{f'(s)ds}{(x-s)^{1-\alpha}}, \quad 0 < \alpha < 1$$

aniq integralni yuqori aniqlikda hisoblashdir. Buning uchun biz quyidagi ko'rinishdagi kvadratur formulani qaraymiz (f' funksiya φ deb olingan)

$$\int_0^t \frac{\varphi(x)dx}{(t-x)^{1-\alpha}} \cong \sum_{\beta=0}^N C_\beta \varphi(h\beta), \quad (3)$$

bu yerda $h\beta$ - tugun nuqtalar, $\beta = 0, \dots, N$, $h = \frac{t}{N}$, $N \in \mathbb{N}$, $t > 0$, C_β kvadratur formulaning koeffitsiyentlari. Bunda φ funksiyalar quyidagicha aniqlangan Gilbert fazosiga tegishli:

$$W_2^{(m,m-1)}(0,t) = \{\varphi \mid \varphi: [0,t] \rightarrow \mathbb{R}, \varphi^{(m-1)} - \text{absolyut uzluksiz}, \varphi^{(m)} \in L_2(0,t)\}$$

Ushbu $W_2^{(m,m-1)}(0,t)$ fazoning f va g funksiyalari uchun skalyar ko'paytma quyidagicha aniqlangan

$$\langle f, g \rangle_{W_2^{(m,m-1)}} = \int_0^t (f^{(m)}(x) + f^{(m-1)}(x))(g^{(m)}(x) + g^{(m-1)}(x))dx. \quad (4)$$

Shuningdek, $W_2^{(m,m-1)}(0,t)$ fazoda (4) skalyar ko'paytmaga mos norma quyidagicha

$$\|\varphi\|_{W_2^{(m,m-1)}} = \left\{ \int_0^t (\varphi^{(m)}(x) + \varphi^{(m-1)}(x))^2 dx \right\}^{1/2}. \quad (5)$$

Integral va kvadratur yig'indi orasidagi quyidagi ayirmaga

$$(\ell, \varphi) = \int_0^t \frac{\varphi(x)dx}{(t-x)^{1-\alpha}} - \sum_{\beta=0}^N C_\beta \varphi(h\beta) \quad (6)$$

(3) kvadratur formulaning **xatoligi** deyiladi, hamda unga

$$\ell(x) = \frac{\varepsilon_{[0,t]}(x)}{(t-x)^{1-\alpha}} - \sum_{\beta=0}^N C_\beta \delta(x-h\beta) \quad (7)$$

ko'rinishdagi **xatolik funksionali** mos keladi. Bu yerda, $\varepsilon_{[0,t]}(x)$ - funksiya $[0,t]$ kesmaning xarakteristik funksiyasi, hamda $\delta(x)$ - Dirakning delta-funksiyasi.

Koshi-Shvars tengsizligiga asosan, quyidagiga ega bo'lamiz

$$|(\ell, \varphi)| \leq \|\varphi\|_{W_2^{(m,m-1)}} \cdot \|\ell\|_{W_2^{(m,m-1)*}}.$$

Demak, $W_2^{(m,m-1)}(0,t)$ fazoda (3) kvadratur formulaning absolyut xatoligi $W_2^{(m,m-1)*}(0,t)$ qo'shma fazodagi ℓ xatolik funksionalining normasi yordamida yuqoridan baholanadi. Bundan quyidagi masalalarga ega bo'lamiz.

1-masala. Gilbert fazosida (3)-kvadratur formulaning (7)-xatolik funksionali normasi $\|\ell\|_{W_2^{(m,m-1)*}}$ ni aniqlash.

2-masala. (7)-xatolik funksionali normasiga minimum qiymat beruvchi $\overset{\circ}{C}_\beta := C_\beta$ koeffitsiyentlarini aniqlash.

Ushbu $W_2^{(m,m-1)}(0,t)$ fazoda (3) kvadratur formulaning ℓ xatolik funksionalining normasini, ya'ni $\|\ell(x)\|_{W_2^{(m,m-1)*}}$ ni eng kichik qiymatga erishtiruvchi $\overset{\circ}{C}_\beta := C_\beta$ koeffitsiyentlarni topish.

Bunda, $\overset{\circ}{C}_\beta$ *optimal koeffitsiyentlar* va unga mos (3)-kvadratur formula *optimal kvadratur formula* deyiladi.

Xatolik funksionalining normasini hisoblash uchun S.L.Sobolev tomonidan kiritilgan ushbu

$$(\ell, \psi_\xi) = \|\ell\|_{W_2^{(m,m-1)*}(0,t)} \cdot \|\psi_\xi\|_{W_2^{(m,m-1)}(0,t)}$$

tenglikni qanoatlantiruvchi ψ_ξ ekstremal funksiya tushunchasidan foydalanamiz.

Qaralayotgan fazo Gilbert fazosi bo'lganligi uchun chiziqli uzluksiz funksionalning umumiy ko'rinishi haqidagi Riss teoremasidan foydalanamiz. Riss teoremasiga asosan $\forall \ell \in W_2^{(m,m-1)*}(0,t)$ chiziqli uzluksiz funksional uchun $W_2^{(m,m-1)}(0,t)$ fazoning o'zida unga mos shunday ψ_ξ funksiya mavjud va u funksiya uchun quyidagi munosabatlar o'rinli

$$(\ell, \varphi) = \langle \psi_\xi, \varphi \rangle_{W_2^{(m,m-1)}}, \quad (8)$$

$$\|\ell\|_{W_2^{(m,m-1)*}} = \|\psi_\xi\|_{W_2^{(m,m-1)}}. \quad (9)$$

Bu yerda $\langle \psi_\xi, \varphi \rangle_{W_2^{(m,m-1)}}$ bu $W_2^{(m,m-1)}$ fazosidagi ψ_ξ va φ funksiyalarning skalyar ko'paytmasi.

Endi biz (8)-tenglamani yechish bilan shug'ullanamiz. (8)-tenglamaning o'ng tomonini bo'laklab integrallash orqali, quyidagi chegaraviy masalaga ega bo'lamiz

$$\psi_\xi^{(2m)}(x) - \psi_\xi^{(2m-2)}(x) = (-1)^m \ell(x), \quad (10)$$

$$(\psi_\xi^{(m+s)}(x) - \psi_\xi^{(m+s-2)}(x))|_0^t = 0, \quad s = \overline{1, m-1}, \quad (11)$$

$$(\psi_\xi^{(m)}(x) - \psi_\xi^{(m-1)}(x))|_0^t = 0. \quad (12)$$

Quyidagi teorema o'rinli

1-teorema. Ushbu $W_2^{(m,m-1)}(0,t)$ fazoda (11)-(12) chegaraviy shartlarda (10)-differensial tenglamaning yechimi (3)-kvadratur formulaning xatolik funksionali ℓ ga mos keluvchi ψ_ξ ekstremal funksiyasi quyidagi ko'rinishga ega

$$\psi_\xi(x) = (-1)^m \ell(x) * G_m(x) + P_{m-2}(x) + de^{-x}, \quad (13)$$

bu yerda

$$G_m(x) = \frac{\operatorname{sgn} x}{2} \left(\frac{e^x - e^{-x}}{2} - \sum_{k=1}^{m-1} \frac{x^{2k-1}}{(2k-1)!} \right), \quad (14)$$

d ixtiyoriy haqiqiy son, $P_{m-2}(x)$ esa $(m-2)$ -darajali ko'phad.

Yuqoridagi teoremda topilgan ekstremal funksiyaning (7) - tenglikka keltirib qo'yib ℓ xatolik funksionali normasining kvadratini hisoblaymiz. Natijada quyidagi teoreмага ega bo'lamiz

2-teorema. Ushbu $W_2^{(m,m-1)}(0,t)$ fazoda (7) xatolik funksionali normasining kvadrati quyidagi ko'rinishga ega bo'ladi

$$\|\ell\|_{W_2^{(m,m-1)*}}^2 = (-1)^m \left[\sum_{\beta=0}^N \sum_{\gamma=0}^N C_\beta C_\gamma G_m(h\beta - h\gamma) - 2 \sum_{\beta=0}^N C_\beta \int_0^t \frac{G_m(x - h\beta) dx}{(t-x)^{1-\alpha}} + \int_0^t \int_0^t \frac{G_m(x-y) dx dy}{(t-x)^{1-\alpha} (t-y)^{1-\alpha}} \right], \quad (15)$$

bu yerda $G_m(x)$ funksiya (14) tenglik bilan aniqlangan.

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КВАДРАТ НОРМЫ ФУНКЦИОНАЛА ПОГРЕШНОСТИ СОСТАВНЫХ ОПТИМАЛЬНЫХ КВАДРАТУРНЫХ ФОРМУЛ

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Рассмотрим следующую экспоненциально весовую квадратурную формулу составной квадратурной формулой называется приближенная формула, выражающая значение интеграла $\int_0^1 \varphi(x) dx$ в виде линейной комбинации значений подынтегральной функций и ее производных в точках, называемых узлами:

$$\int_0^1 \varphi(x) dx \cong \sum_{k=1}^N \sum_{\alpha}^t C_k^{(\alpha)} \varphi^{(\alpha)}(x_k), \quad (0.1)$$

или

$$\int_{-\infty}^{\infty} \varepsilon_{[0,1]}(x) \varphi(x) dx \cong \sum_{k=1}^N \sum_{\alpha}^t C_k^{(\alpha)} \varphi^{(\alpha)}(x_k)$$

где $\varepsilon_{[0,1]}$ — индикатор (или характеристическая функция) отрезка $[0,1]$, $t \leq m-1$. Узлы x_k называют узлами квадратурной формулы, а числа $C_1^{(\alpha)}, C_2^{(\alpha)}, \dots, C_N^{(\alpha)}$ — ее коэффициентами, $\varphi(x) \in \tilde{L}_2^{(m)}(0,1)$.

Напомним, что функция $f(x)$ называется 1-периодической, если для любого целого $\beta \in \mathbb{Z}$ и всех x выполняется $f(x) = f(x + \beta)$. Приводим определения 1- периодического пространства Соболева $\tilde{L}_2^{(m)}(0,1)$.

Пространство $\tilde{L}_2^{(m)}(0,1)$ при $m \geq 1$ — гильбертово пространство 1- периодических функций $f(x)$, $-\infty < x < \infty$, отличающихся более, чем на константу, m — производные (в обобщенном смысле) квадратично интегрируемы со скалярным произведением

$$(f, g) = \int_0^1 \frac{d^m f}{dx^m} \frac{d^m g}{dx^m} dx$$

Норма в пространстве $\tilde{L}_2^{(m)}(0,1)$ определяется формулой

$$\| \varphi \|_{\tilde{L}_2^{(m)}(0,1)}^2 = (\varphi, \varphi).$$

$$\| \varphi \|_{\tilde{L}_2^{(m)}(0,1)}^2 = \int_0^1 \left(\frac{d^m}{dx^m} \varphi(x) \right)^2 dx.$$

Погрешностью квадратурной формулы называют разность

$$\begin{aligned} (\ell, \varphi) &= \int_0^1 \varphi(x) dx - \sum_{k=1}^N \sum_{\alpha=0}^t C_k^{(\alpha)} \varphi^{(\alpha)}(x_k) = \\ &= \int_{-\infty}^{\infty} \left(\varepsilon_{[0,1]}(x) - \sum_{k=1}^N \sum_{\alpha=0}^t C_k^{(\alpha)} (-1)^\alpha \delta^{(\alpha)}(x - x_k) * \phi_0(x) \right) \varphi(x) dx. \end{aligned}$$

Где $\delta(x)$ — дельта функция Дирака, $\phi_0(x) = \sum_{\beta} \delta(x - \beta)$,

$$\ell(x) = \left(\varepsilon_{[0,1]}(x) - \sum_{k=1}^N \sum_{\alpha=0}^t C_k^{(\alpha)} (-1)^\alpha \delta^{(\alpha)}(x - x_k) \right) * \phi_0(x). \quad (0.2)$$

В настоящей работе результаты интегрированию периодических функций полученных функциональными методами из [1,2] обобщаются на случай составных квадратурных формул. Для квадрат нормы функционала погрешности (1.2) оптимальных квадратурных формул справедливы следующие теоремы.

Теорема 1. Квадрат нормы функционала погрешности оптимальных квадратурных формул вида (1.2) при $t = 0.1$ имеет вид

$$\|\ell\|_{\tilde{L}_2^{(m)*}(0,1)}^2 = \frac{h^{2m} |B_{2m}|}{(2m)!}.$$

Теорема 2. Квадрат нормы функционала погрешности составных квадратурных формул вида (1.1) при $t = 2$ имеет вид

$$\|\ell\|_{\tilde{L}_2^{(m)*}(0,1)}^2 = \frac{h^{2m}}{(2m)!} \left(|B_{2m}| - \frac{|B_{2m-2}|^2}{|B_{2m-4}|} \frac{(2m-1)2m}{(2m-2)(2m-3)} \right).$$

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TRIGONOMETRIC FUNDAMENTAL SPLINES ON RECTANGULAR FINITE ELEMENTS

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Let us be given a domain $\Omega = [0,1] \times [0,1] \subset \mathbb{R}^2$ and a mesh

$$\Delta_{h_1, h_2} := \{(x_i, y_j) : x_i = ih_1, y_j = jh_2, i = 0, 1, \dots, m, j = 0, 1, \dots, n, h_1 m = 1, h_2 n = 1\}$$

in this domain.

Theorem 1. For the trigonometric fundamental splines $\varphi_{i,j}(x,y)$ in the domain Ω , the following relations hold:

$$\begin{aligned} \sum_{i=0}^m \sum_{j=0}^n \varphi_{i,j}(x,y) \sin(\omega_1 x_i) \sin(\omega_2 y_j) &= \sin(\omega_1 x) \sin(\omega_2 y), \\ \sum_{i=0}^m \sum_{j=0}^n \varphi_{i,j}(x,y) \cos(\omega_1 x_i) \cos(\omega_2 y_j) &= \cos(\omega_1 x) \cos(\omega_2 y), \\ \sum_{i=0}^m \sum_{j=0}^n \varphi_{i,j}(x,y) \sin(\omega_1 x_i) \cos(\omega_2 y_j) &= \sin(\omega_1 x) \cos(\omega_2 y), \\ \sum_{i=0}^m \sum_{j=0}^n \varphi_{i,j}(x,y) \cos(\omega_1 x_i) \sin(\omega_2 y_j) &= \cos(\omega_1 x) \sin(\omega_2 y), \end{aligned}$$

where

$$\varphi_{i,j}(x,y) = \varphi_i \otimes \varphi_j(x,y) = \varphi_i(x) \varphi_j(y) (i = 0, 1, \dots, m; j = 0, 1, \dots, n),$$

$\varphi_i(x)$ and $\varphi_j(y)$ are determined using expressions (17)–(19) in the work [1], ω_1 and ω_2 are elements of the set $\mathbb{R} \setminus \{0\}$.

It should be noted that the basis functions $\varphi_{i,j}(x,y)$ ($i = 0, 1, \dots, m, j = 0, 1, \dots, n$) can be applied to finite element methods.

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ON RADIALLY SYMMETRIC SOLUTIONS FOR AN ELLIPTIC EQUATION WITH $P(|X|)$ -LAPLACIAN

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Let us consider the following Dirichlet problem

$$-div\left(|\nabla u|^{p(|x|)-2}\nabla u\right)=F(x,u,\nabla u), \quad x\in B_R\subset R^n \quad (1)$$

$$u=0 \text{ on } \partial B_R \quad (2)$$

where B_R is a ball of radius R , ∂B_R is the boundary of B_R , $p(|x|)>2$.

The presence of gradient terms in the equation significantly complicates the application of variational methods to study the solvability of the problem (1). We also note that the equation in (1) has an important property: it is not scale-invariant, which makes inapplicable many traditional methods for studying solvability and analyzing the qualitative properties of solutions.

We are interested in the existence of bounded radially symmetric solutions of problem (1). We will assume that the function $F(x,u,\nabla u)$ can be represented as $F(r,u,u_r)$ under the change of variables $r=|x|$. In what follows, we will denote the derivative of the function u with respect to the variable r as u' . It is well known that the bounded radially symmetric solution of (1) satisfies the equation

$$-\left(|u'|^{p(r)-2}u'\right)' - \frac{n-1}{r}|u'|^{p(r)-2}u' = F(r,u,u') \quad r\in(0,R) \quad (3)$$

$$u'(0)=u(R)=0. \quad (4)$$

One of the standard conditions in the study of the solvability of the problem (1) is the Bernstein--Nagumo condition imposed on the function $F(r,u,u')$,

$$|F(r,u,u')|\leq c|1+|q|^p| \quad \text{for } (r,u,q)\in[0,R]\times[-M,M]\times R$$

with some constant c , provided that the solution satisfies the condition $\max u\leq M$ with some constant M . We are interested in the solvability of (1) without any smallness conditions in the case where the function $F(r,u,q)$ has arbitrary growth with respect to the variable q .

We do not impose any restrictions on the right-hand side of (2) that would guarantee the sign certainty of both the solution itself and its derivative. Thus, we seek its solutions in the class of weak Sobolev solutions.

Under certain conditions on the right-hand side, related to monotonicity in the variable u , replacing (4), it is possible to prove the existence of a weak Sobolev solution that has a classical derivative continuous in the sense of Holder.

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**KOMPAKT BO‘LMAGAN QO‘ZG‘ALISHGA EGA UCHINCHI TARTIBLI
OPERATORLI MATRITSA KANAL OPERATORINING SPEKTRI**

Sayliyeva G.R.

Annotatsiya. Ushbu tezisda kompakt bo'lmagan qo'zg'alishga ega uchinchi tartibli $H_{\mu,\lambda}$ operatorli matritsaning spektrini o'rganishda muhim bo'lgan kanal operatori va kanal operatorining spektri o'rganilgan. Shuningdek, kanal operatorining spektri hamda $H_{\mu,\lambda}$ operatorining muhim spektri orasidagi bog'lanishni tavsiflovchi teorema keltirilgan.

$\mathbb{T}^d$ orqali d o'lchamli torni, $\mathbb{C}$ orqali bir o'lchamli kompleks sonlar to'plamini, $L_2(\mathbb{T}^d)$ orqali $\mathbb{T}^d$ torda aniqlangan kvadrati bilan integrallanuvchi (kompleks qiymatli) funksiyalarning Hilbert fazosini, $L_2^S((\mathbb{T}^d)^2)$ orqali $(\mathbb{T}^d)^2$ torda aniqlangan kvadrati bilan integrallanuvchi, (kompleks qiymatli) simmetrik funksiyalarning Hilbert fazosini belgilaymiz. Quyidagi

$$\mathcal{H}_0 := \mathbb{C}, \quad \mathcal{H}_1 := L_2(\mathbb{T}^d), \quad \mathcal{H}_2 := L_2^S((\mathbb{T}^d)^2)$$

$\mathcal{H}_0, \mathcal{H}_1, \mathcal{H}_2$ Hilbert fazolarning to'g'ri yig'indisidan tashkil topgan $\mathcal{H}$ fazoni qaraymiz:

$$\mathcal{H} := \mathcal{H}_0 \oplus \mathcal{H}_1 \oplus \mathcal{H}_2.$$

$\mathcal{H}$ fazoda aniqlangan

$$H_{\mu,\lambda} := \begin{pmatrix} H_{00} & \mu H_{01} & 0 \\ \mu H_{01}^* & H_{11} & \mu H_{12} \\ 0 & \mu H_{12}^* & H_{22}^0 - \lambda V \end{pmatrix}$$

operatorli matritsani qaraymiz. Uning matritsaviy elementlari quyidagicha aniqlangan:

$$H_{00}f_0 = \omega_0 f_0, \quad H_{01}f_1 = \int_{\mathbb{T}^d} v_0(t) f_1(t) dt, \quad (H_{11}f_1)(x) = \omega_1(x) f_1(x);$$

$$(H_{12}f_2)(x) = \int_{\mathbb{T}^d} v_1(t) f_2(x, t) dt, \quad (H_{22}^0 f_2)(x, y) = \omega_2(x, y) f_2(x, y);$$

$$V := V_1 + V_2, \quad (V_1 f_2)(x, y) = v_2(x) \int_{\mathbb{T}^d} v_2(t) f_2(t, y) dt;$$

$$(V_2 f_2)(x, y) = v_2(y) \int_{\mathbb{T}^d} v_2(t) f_2(x, t) dt.$$

Bu yerda μ va λ parametrlar musbat haqiqiy sonlar, ω_0 biror fikslangan haqiqiy son, $v_0(\cdot), \omega_1(\cdot), v_1(\cdot), v_2(\cdot)$ funksiyalar $\mathbb{T}^d$ torda aniqlangan haqiqiy qiymatli uzluksiz funksiyalar, $\omega_2(\cdot, \cdot)$ esa $(\mathbb{T}^d)^2$ torda aniqlangan haqiqiy qiymatli uzluksiz, simmetrik funksiyadir.

$H_{\mu,\lambda}$ operator chiziqli, chegaralangan va o'z-o'ziga qo'shma operatoridir. V_1 va V_2 operatorlar $L_2((\mathbb{T}^d)^2)$ Hilbert fazosida ta'sir qiluvchi xususiy integralli operatoridir. Demak, V_1 va V_2 lar kompakt bo'lmagan operatoridir.

Quyidagicha belgilashlar kiritamiz:

$$\hat{\mathcal{H}}_1 := \mathcal{H}_1, \quad \hat{\mathcal{H}}_2 := L_2((\mathbb{T}^d)^2), \quad \hat{\mathcal{H}} := \hat{\mathcal{H}}_1 \oplus \hat{\mathcal{H}}_2.$$

$H_{\mu,\lambda}$ operatorning spektrini aniqlashda muhim bo'lgan $H_{\mu,\lambda}^{\text{ch}}$ kanal operatori deb ataluvchi operatorni qaraymiz:

$$H_{\mu,\lambda}^{\text{ch}} = \begin{pmatrix} H_{11} & \frac{\mu}{\sqrt{2}} H_{12} \\ \frac{\mu}{\sqrt{2}} H_{21} & H_{22}^0 - \lambda V_2 \end{pmatrix}, \quad (H_{21}f_1)(x, y) = v_1(x) f_1(x).$$

$H_{\mu,\lambda}^{\text{ch}}$ kanal operatori $\hat{\mathcal{H}}$ fazodagi U_φ ko'paytirish operatori bilan o'rin almashinish xossasiga ega bo'lganligi uchun, uni quyidagicha to'g'ri integral yig'indiga yoyishimiz mumkin [2,3]:

$$H_{\mu,\lambda}^{\text{ch}} = \int_{\mathbb{T}^d} \oplus (h_{\mu,\lambda}(x)) dx.$$

Bunda $h_{\mu,\lambda}(x), x \in \mathbb{T}^d$ umumlashgan Fridriks modellari oilasi deb ataladi va $\hat{\mathcal{H}}$ fazoda

$$h_{\mu,\lambda}(x) := \begin{pmatrix} h_{00}(x) & \frac{\mu}{\sqrt{2}} h_{01} \\ \frac{\mu}{\sqrt{2}} h_{10} & h_{11}(x) - \lambda \vartheta_2 \end{pmatrix}$$

kabi aniqlanadi, uning matritsaviy elementlari esa

$$h_{00}(x)f_0 = \omega_1(x)f_0, \quad h_{01}f_1 = \int_{\mathbb{T}^d} v_1(t) f_1(t) dt, \quad (h_{10}f_0)(x) = v_1(x) f_0;$$

$$(h_{11}(x) f_1)(y) = \omega_2(x, y) f_1(y), \quad (\vartheta_2 f_1)(y) = v_2(y) \int_{\mathbb{T}^d} v_2(t) f_1(t) dt$$

tengliklar orqali ta'sir qiladi.

Quyidagi teorema $h_{\mu,\lambda}(x)$ operatorning diskret spektri $\sigma_{\text{disc}}(h_{\mu,\lambda}(x))$ yordamida $H_{\mu,\lambda}^{\text{ch}}$ kanal operatorining spektrini tavsiflaydi.

1-teorema. $H_{\mu,\lambda}^{\text{ch}}$ kanal operator sof muhim spektrga ega va $\sigma(H_{\mu,\lambda}^{\text{ch}})$ uchun quyidagi

$$\sigma(H_{\mu,\lambda}^{\text{ch}}) = \bigcup_{x \in \mathbb{T}^d} \sigma_{\text{disc}}(h_{\mu,\lambda}(x)) \cup \left[\min_{x,y \in \mathbb{T}^d} \omega_2(x, y), \max_{x,y \in \mathbb{T}^d} \omega_2(x, y) \right]$$

tenglik o'rinli.

Ishning 2-asosiy natijasini bayon qilamiz.

2-teorema. $H_{\mu,\lambda}$ operatorli matritsaning muhim spektri $H_{\mu,\lambda}^{\text{ch}}$ kanal operator spektriga tengdir, ya'ni

$$\sigma_{\text{ess}}(H_{\mu,\lambda}^{\text{ch}}) = \sigma(H_{\mu,\lambda}^{\text{ch}}).$$

Oxirgi teorema $\sigma_{\text{ess}}(H_{\mu,\lambda}^{\text{ch}})$ to'plamni tashkil qiluvchi kesmalar soni va joylashuv o'rnini tahlil qilishda muhim ahamiyatga ega.

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ЗАДАЧА ДИРИХЛЕ ДЛЯ НАГРУЖЕННОГО УРАВНЕНИЯ ЭЛЛИПТИЧЕСКОГО ТИПА С ОДНИМ СИНГУЛЯРНЫМ КОЭФФИЦИЕНТОМ

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Аннотация. В данной работе установлены необходимые и достаточные условия единственности и существования решения для нагруженного уравнения эллиптического типа с одним сингулярным коэффициентом в прямоугольной области.

Рассмотрим уравнение

$$u_{xx} + u_{yy} + \frac{2\alpha}{x} u_x + c(y) u(x, 0) = 0 \quad (1)$$

в прямоугольной области $D = \{(x, y) : x \in (0, a), y \in (0, b)\}$, где $a, b \in \mathbb{R}^+$, $\alpha \in (0, 1/2)$, $c(y)$ – заданная функция.

Уравнение (1) в области D является уравнением эллиптического типа с одним сингулярным коэффициентом с нагруженным членом.

Для уравнения (1) в области D , сформулируем и исследуем следующую задачу:

Задача Дирихле. Найти функцию $u(x, y)$, удовлетворяющую в области D уравнению (1) и условиям

$$\begin{aligned} u(x, y) &\in C(\bar{D}) \cap C_{x,y}^{2,2}(D), \\ u(0, y) &= 0, \quad u(a, y) = 0, \quad 0 \leq y \leq b, \\ u(x, 0) &= \varphi_1(x), \quad u(x, b) = \varphi_2(x), \quad 0 \leq x \leq a. \end{aligned}$$

Отметим, что в работе [1] для нагруженного парабола-гиперболического уравнения в прямоугольной области изучена начально-граничная задача, в которой методом спектральных разложений [2] установлен критерий единственности решения этой задачи, и само решение построено в виде суммы ряда по собственным функциям соответствующей одномерной задачи на собственные значения.

Доказана следующая теорема.

Теорема. Пусть $\alpha \in (0, 1/2)$ и выполнены следующие условия:

1. $c(y) \in C[0, b]$ и это функция достаточно мала по норме $\|c\|_{C[0,b]} \leq \varepsilon$, где $\varepsilon > 0$ – достаточно малое число;
2. $\varphi_1, \varphi_2 \in C^2[0, a]$ и выполнены условия согласования: $\varphi_1(0) = \varphi_1(a) = 0$, $\varphi_2(0) = \varphi_2(a) = 0$.

Тогда решение задачи Дирихле будет однозначно разрешима.

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АНАЛОГ ТЕОРЕМЫ ОСТРОВСКОГО ДЛЯ РЯДОВ ПО ОДНОРОДНЫМ ПОЛИНОМАМ

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Данная заметка посвящена многомерным аналогам теоремы Островского о лакунарных рядах. В работе исследуются области существования лакунарных рядов по однородным полиномам с лакунами Островского. Приводятся аналоги теоремы Островского для таких рядов и описываются области сходимости этих рядов.

Пусть на плоскости задан следующий степенной ряд

$$f(z) = \sum_{n=0}^{\infty} c_n z^n, \quad \overline{\lim}_{n \rightarrow \infty} |c_n|^{\frac{1}{n}} = 1. \quad (1)$$

Определение 1. Ряд (1) называется лакунарным, если существует строго возрастающая последовательность натуральных чисел $\{n_k\}$ такая, что

$$c_n = 0, \text{ если } n \notin \{n_k\}.$$

Определение 2. Говорят, что степенной ряд (1) имеет лакуны Островского, если существуют две строго возрастающие последовательности $\{n_k\}$ и $\{n'_k\}$ натуральных чисел, такие что

$$c_n = 0, \text{ если } n_k < n \leq n'_k \quad (k=0, 1, 2, \dots).$$

и

$$\lim_{k \rightarrow \infty} \frac{n_k}{n'_k} = 0. \quad (2)$$

Рассмотрим формальный лакунарный ряд

$$\sum_{k=0}^{\infty} \mathbb{Q}_{n_k}(z) \quad (3)$$

по однородным полиномам $\mathbb{Q}_{n_k}(z)$ и будем исследовать область сходимости такого ряда.

В работе [1] Й.Сичак рассмотрел следующую задачу. Пусть функция n комплексных переменных $f(z)$ голоморфна в окрестности нуля и разложена в лакунарный ряд по однородным полиномам

$$f(z) = \sum_{k=0}^{\infty} \mathbb{Q}_{n_k}(z) \quad (4)$$

Пусть $\psi(z) := \overline{\lim_{k \rightarrow \infty}} |\mathbb{Q}_{n_k}(z)|^{\frac{1}{n_k}}$ и $h(z) := \psi^*(z)$ – регуляризация функции ψ . Тогда известно, что круговая область

$$D := \{z \in \mathbb{C}^n : h(z) < 1\}$$

является областью сходимости ряда (4). Для этого ряда имеет место следующий многомерный аналог теоремы Фабри.

Теорема 1. (Сичак [1]). Если для ряда (4)

$$\overline{\lim_{k \rightarrow \infty}} \frac{k}{n_k} = \lim_{k \rightarrow \infty} \frac{k}{n_k} = 0,$$

то область сходимости D ряда (4) совпадает с естественной областью существования W_f функции $f(z)$.

В работе [2], используя комплексную теорию плюрипотенциала, приводится более простое доказательство этой теоремы и рассматривается аналог теоремы в более общих ситуациях, приводится аналог теоремы Поля (случай, когда $\lim_{k \rightarrow \infty} \frac{k}{n_k} = 0$). В случае, когда

$\lim_{k \rightarrow \infty} \frac{k}{n_k} = 0$, ряд (4) может сходиться и вне области D , т.е. D не будет естественной областью существования функции f . Тем не менее, в работе [2] доказано, что f является однозначной функцией в $\mathbb{C}^n$, т.е. $W_f \subset \mathbb{C}^n$ и дается простое описание W_f в терминах $W_{f,\ell}$, $\ell \in \mathbb{P}^{n-1}$.

Основным результатом работы является аналог теоремы Поля для лакунарного ряда Островского по однородным полиномам с переменным радиусом сходимости.

Теорема 2. Пусть ряд (4) и семейство комплексных прямых $\mathcal{L} \subset \mathbb{P}^{n-1}$ удовлетворяют следующим условиям

- 1) $\mathcal{L}$ не является плюриполярным,
- 2) ряд (4) имеет лакуны Островского,
- 3) для каждой прямой $\ell \in \mathcal{L}$ ряд (4) сходится в круге положительного радиуса $R(\ell) \geq r > 0$.

Тогда ряд (4) определяет однозначную голоморфную функцию $f(z)$ в $\mathbb{C}^n$, т.е. естественная область существования W_f функции f однолистная, $W_f \subset \mathbb{C}^n$. Более того,

- 1) $0 \in W_f$,
- 2) W_f совпадает с открытым ядром объединения $\bigcup_{\ell \ni 0} W_{f,\ell}$, т.е.

$$W_f = \left(\bigcup_{\ell \in \mathbb{P}^{n-1}} W_{f,\ell} \right)^0,$$

3) для всех комплексных прямых $\ell \in \mathbb{P}^{n-1}$ за исключением некоторого плюриполярного множества $P \subset \mathbb{P}^{n-1}$,

$$\ell \cap W_f = W_{f,\ell}, \quad \ell \notin P.$$

Для доказательства этой теоремы нам нужно следующее утверждение, доказанное в работе [2].

Теорема 3. Пусть задан формальный ряд

$$\sum_{s=0}^{\infty} Q_s(z)$$

по однородным полиномам Q_s и семейство $\mathcal{L} \subset \mathbb{P}^{n-1}$ комплексных прямых ℓ . Если для каждой комплексной прямой $\ell \in \mathcal{L}$ ряд $\sum_{s=0}^{\infty} Q_s(z) \big|_{\ell}$ сходится в круге $\ell \cap B(0, r(l))$, $0 < r(l) \leq 1$, то он равномерно сходится внутри области

$$\Omega = \{z \in \mathbb{C}^n : |z| \cdot \exp V^*\left(\frac{z}{|z|}, E\right) < 1\}, \quad (5)$$

где $E = \bigcup_{l \in \mathcal{L}} (l \cap S(0, r(l)))$, $S(0, r(l)) = \partial B(0, r(l))$ и $V^*(z, E)$ функция Грина множества E (или экстремальная функция Сичака - Захарюты).

Так как обобщенная функция Грина $V^*(z, E) \equiv +\infty$ тогда и только тогда, когда E плюриполярное множество в $\mathbb{C}^n$, то из равенства (5) видно, что теорема 3 содержательна лишь тогда, когда множество E является неплюриполярным в $\mathbb{C}^n$, что и мы будем предполагать. Исключаем также тривиальный случай, когда $\Omega = \mathbb{C}^n$.

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O'ZGARMAS KECHIKUVCHI ARGUMENTLI BIR O'LCHOVLI GIPERBOLIK TURDAGI TENGLAMA UCHUN BIRINCHI BOSHLANG'ICH-CHEGARAVIY MASALA Yangiboyev Z.SH., Toshqulova D.

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Annotatsiya. Ushbu maqolada o'zgarmas koeffitsientli va o'zgarmas kechikuvchi argumentli bir o'lchovli giperbolik tipdagi chiziqli tenglama uchun birinchi boshlang'ich-chegaraviy masala qaraladi. Masalaning yechimi Furiye usuli va qadamlar usuli (method of steps) yordamida quriladi. Yechimning mavjudligi va yagonaligi tegishli teoremlar bilan asoslanadi.

Kechikuvchi argumentli giperbolik tenglamalar signallar yoki ta'sirlarning cheklangan tezlikda tarqalishi bilan bog'liq jarayonlarni modellashtirishda muhim ahamiyat kasb etadi. Ushbu tenglamalar biologiyada populyatsiya dinamikasi va hujayra sikllarini, neyrobiologiyada nerv impulslarining uzatilishini, muhandislikda elektr uzatish liniyalari va tebranishlarni boshqarish tizimlarini hamda akustikada musiqa asboblarini raqamli sintez qilishni tavsiflashda keng qo'llaniladi. Shuningdek, termoelastiklik, transport oqimlari va iqtisodiy sikllar kabi sohalaridagi dinamik jarayonlar ham mazkur turdagi tenglamalar orqali ifodalanadi. Ishda qaralayotgan masalaning yechimi qadamlar usuli asosida quriladi va uning mavjudligi hamda yagonaligi isbotlanadi. Olingan natijalar kechikuvchi dinamik tizimlarni tadqiq etish va amaliy masalalarni yechishda nazariy asos bo'lib xizmat qiladi.

Masalaning qo'yilishi. $D = \{(x, y), 0 < x < l, t > 0\}$ sohada

$$\frac{\partial^2 u}{\partial t^2} = a_1 \frac{\partial^2 u}{\partial x^2} + a_2 \frac{\partial^2 w}{\partial x^2} + b_1 u + b_2 w + f(x, t), w = u(x, t\tau), 0 < \tau < 1, \quad (1)$$

ko'rinishdagi o'zgaras koeffitsiyentli va o'zgaras kechikuvchili giperbolik tipdagi bir o'lovli chiziqli tenglama uchun boshlang'ich-chegaraviy masalani ko'rib chiqaylik, bu yerda $a_1 \geq 0, a_2 \geq 0, a_1 + a_2 \geq 0$.

(1) tenglamani $t > \tau$ da

$$u|_{x=0} = \nu_1(t), u|_{x=l} = \nu_2(t), \quad (2)$$

birinchi turdagi bir jinsli bo'lmagan chegaraviy shartlari va $0 < x < l, 0 \leq t < \tau$ da

$$u = \varphi(x, t), \frac{\partial u}{\partial t} = \psi(x, t) \quad (3)$$

umumiy boshlang'ich shartlar bilan to'ldiramiz. (1) tenglamaga va (3) boshlang'ich shartga kiritilgan f va φ, ψ funktsiyalar uzluksiz, (2) chegaraviy shartdagi $\nu_1(t), \nu_2(t)$ funktsiyalar t ga nisbatan uzluksiz differensiallanuvchi deb faraz qilamiz. Bundan tashqari, (2) chegaraviy va (3) boshlang'ich shartlar muvofiqlik shartlarini qanoatlantiradi, ya'ni

$$\begin{aligned} \nu_1(l) &= \varphi(l, 0), \nu_2(0) = \varphi(l, 0), \\ \nu_1'(0) &= \psi(0, 0), \nu_2'(0) = \psi(l, 0) \end{aligned} \quad (4)$$

munosabatlari bajariladi deb faraz qilamiz.

Ushbu masalaning yechimini yagonaligi uchun quyidagi teorema o'rinli:

Teorema. Faraz qilaylik, $l > 0, \tau \in (0, l)$ bo'lib, quyudagi shartlar bajarilsin:

1. Tenglamaning koeffitsiyentlari $a_1 \geq 0, a_2 \geq 0$ va $a_1 + a_2 > 0$ shartlarni qanoatlantirsin; $b_1, b_2 \in \mathbb{R}$ — ixtiyoriy o'zgaras sonlar.
2. Ozod had $f(x, t) \in C(\bar{D})$ bo'lsin, boshlang'ich funktsiyalar $\varphi, \psi \in C(\bar{D}_\tau)(D_\tau = (0, l) \times [0, \tau))$ bo'lib, quyidagi silliqlik shartlarini qanoatlantirsin:

$$\varphi \in C^{2,1}(\bar{D}_\tau), \psi \in C^{1,0}(\bar{D}_\tau).$$

3. Chegaraviy funktsiyalar $\nu_1(t), \nu_2(t) \in C^2([0, \infty))$ sinfga tegishli bo'lsin va (4) muvofiqlik shartlari bajarilsin. U holda (1)-(3) boshlang'ich-chegaraviy masala D sohada yagona klassik yechimga ega bo'ladi.

Bu yechim quyidagi xossalarga ega bo'ladi:

1. Har bir $k \in \mathbb{N} \cup \{0\}$ uchun $u \in C^{2,2}((0, l) \times (k\tau, (k+1)\tau) \cap C([0, l] \times [k\tau, (k+1)\tau]));$
2. $u(x, t)$ funksiya $(x, t) \in (0, l) \times (k\tau, (k+1)\tau)$ da tenglamani qanoatlantiradi;
3. $u(x, t)$ berilgan boshlang'ich va chegaraviy shartlarni qanoatlantiradi;
4. $t = k\tau$ kesimlarda yechim va uning vaqt bo'yicha birinchi tartibli hosilasi uzluksiz tutashadi.

Isbot kechikuvchi argumentli differensial tenglamalar uchun standart qadamlar usuli (method of steps) yordamida amalga oshiriladi. $[0, \tau)$ oraliqda $w(x, t) = \varphi(x, t - \tau)$ ma'lum bo'lgani sababli masala oddiy giperbolik tenglamaga aylanadi va klassik natijalarda ko'ra yagona yechim mavjud. Keyingi har bir $[k\tau, (k+1)\tau]$ oraliqda $w(x, t)$ oldingi qadamda topilgan yechim orqali ifodalanadi va masala yana standart giperbolik tenglama uchun boshlang'ich-chegaraviy masalaga keladi. Induksiya bo'yicha butun $t > 0$ yarim o'qida yechim mavjud va yagona bo'ladi.

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BESSEL OPERATORI VAQT BO'YICHA TA'SIR QILUVCHI YUQORI TARTIBLI GIPERBOLIK TIPDAGI TENGLAMA UCHUN GURSA MASALASI

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Annotatsiya. Yuqori tartibli chiziqli giperbolik xususiy hosilali differensial tenglamalar zamonaviy matematik fizikaning fundamental muammolaridan biri bo'lib, to'liq tarqalishi, elastiklik nazariyasi, elektromagnit dinamika va kvant mexanikasi kabi sohalarida keng qo'llaniladi.

Ushbu maqolada Gursa masalasini Riman usuli bilan yechishni ko'rib chiqamiz. Bu ko'rinishdagi masalani Riman usuli bilan yechish ilgari o'rganilmagan.

$\Omega = \{(x, t) : t < |x|\}$ sohada $u(x, t)$ noma'lum bo'lgan, quyidagi tenglamaning yechimini topishga qaratilgan Gursa masalasini ko'ramiz:

$$L_{\beta}^{\lambda}(u) \equiv \left(\frac{\partial^2}{\partial t^2} + \frac{2\beta}{t} \frac{\partial}{\partial t} - \frac{\partial^2}{\partial x^2} \right)^m u(x, t) - \lambda u(x, t) = 0, \quad (1)$$

bu yerda $\beta, \lambda \in \mathbb{R}$, $0 < \beta < 1/2$.

Gursa masalasi. (1) tenglamani ushbu

$$\left. \frac{\partial^k u}{\partial n^k} \right|_{t=x} = \varphi_k(x), \quad \left. \frac{\partial^k u}{\partial n^k} \right|_{t=-x} = \psi_k(x), \quad x \in (0, \infty), \quad k = \overline{0, m-1}, \quad (2)$$

shartlarni qanoatlantiruvchi $u(x, t) \in C^{2m}(\Omega) \cap C^{2m-1}(\overline{\Omega})$ yechimi topilsin.

$$I_{\eta, \alpha} \varphi(x) = \frac{2x^{-2(\eta+\alpha)}}{\Gamma(\alpha)} \int_0^x (x^2 - t^2)^{\alpha-1} t^{2\eta+1} \varphi(t) dt \quad \text{Erdeyli - Kober operatoridan foydalanib (1) tenglamani}$$

quyidagi ko'rinishga keltirib olamiz

$$L_0^{\lambda}(v) \equiv \left(\frac{\partial^2}{\partial t^2} - \frac{\partial^2}{\partial x^2} \right)^m v(x, t) - \lambda v(x, t) = 0, \quad (x, t) \in \Omega,$$

$v(x, t) = w(\xi, \eta)$, $\xi = x+t$, $\eta = x-t$ xarakteristik koordinatalarga o'tamiz va Riman funksiyasini quramiz.

Riman funksiyasi $R(\xi, \eta; \xi_0, \eta_0)$ quyidagi shartlarni qanoatlantiruvchi qo'shma tenglamaning yechimi hisoblanadi

$$M(R) \equiv \frac{\partial^{2m}}{\partial \xi^m \partial \eta^m} R - \frac{\lambda}{4^m} R = 0,$$

$$\left. \frac{\partial^{n_1} R}{\partial \xi^{n_1}} \right|_{\xi=\xi_0} = 0, \quad n_1 = \overline{0, m-2}, \quad \left. \frac{\partial^{m-1} R}{\partial \xi^{m-1}} \right|_{\xi=\xi_0} = \frac{(\eta - \eta_0)^{m-1}}{(m-1)!},$$

$$\left. \frac{\partial^{n_1} R}{\partial \xi^{n_1}} \right|_{\eta=\eta_0} = 0, \quad \left. \frac{\partial^{m-1} R}{\partial \eta^{m-1}} \right|_{\eta=\eta_0} = \frac{(\xi - \xi_0)^{m-1}}{(m-1)!},$$

u quyidagi ko‘rinishda aniqlangan

$$R(x, t; x_0, t_0) = \left[(x - x_0)^2 - (t - t_0)^2 \right]^{m-1} e_{m, -m}^{m, m} \left[\lambda \left((x - x_0)^2 - (t - t_0)^2 \right)^m \right].$$

Riman funksiyasi Rayt tipidagi funksiya orqali ifodalangan bo‘lib, qator ko‘rinishida quyidagicha bo‘ladi

$$e_{\alpha, \beta}^{\mu, \delta}(z_0) = \sum_{n=0}^{\infty} \frac{z_0^n}{\Gamma(\alpha n + \mu) \Gamma(\delta - \beta n)}, \quad \alpha > \beta, \quad \alpha > 0, \quad z_0 \in C.$$

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NONLOCAL PROBLEM FOR A PARABOLIC-HYPERBOLIC TYPE EQUATION WITH THE CAPUTO OPERATOR IN A RECTANGULAR DOMAIN

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Consider the following equation of mixed parabolic-hyperbolic type with the Caputo operator

$$Lu = \begin{cases} D_t^p u - u_{xx} = 0, & 0 < t < \beta \\ u_{tt} - u_{xx} = 0, & -\alpha < t < 0 \end{cases} \quad (1)$$

in a rectangular region $D = (x, t) \in D_+ \mid 0 < x < 1, -\alpha < t < \beta$, where $\alpha > 0$ and $\beta > 0$ are given real numbers. Let $0 < \rho < 1$ and $D_+ = D \cap \{t > 0\}$, $D_- = D \cap \{t < 0\}$

Definition 1.1. The regulated fractional derivative (Caputo derivative) is determined using the formula:

$$D_{0t}^p h(z) = \frac{1}{\Gamma(1-p)} \int_0^t (t-z)^{-p} h'(z) dz$$

Problem 1.1. Find in the domain D a function $u(x, t)$ satisfying the following conditions:

$$u(x, t) \in C_{x,t}^{2,2}(D_-) \cap C_{x,t}^{2,1}(D_+), \quad (2)$$

$$Lu(x, t) \equiv 0, \quad (x, t) \in (D_+) \cup D_-, \quad (3)$$

$$u(0, t) = u(1, t) = 0, \quad -\alpha \leq t \leq \beta, \quad (4)$$

$$\lim_{t \rightarrow +0} u(x, t) = \lim_{t \rightarrow -0} u(x, t), \quad \lim_{t \rightarrow +0} D_t^p u(x, t) = \lim_{t \rightarrow -0} u_t(x, t), \quad (5)$$

$$au(x, -\alpha) - bu(x, \beta) = \varphi(x), \quad 0 \leq x \leq 1, \quad (6)$$

where a and b are arbitrary constant numbers, $\varphi(x)$ is a given sufficiently smooth function, and

$$\varphi(0) = \varphi(1) = 0.$$

In gas dynamics F.I. Frankl [1] for the Chaplygin equation:

$$k(y)u_{xx} - u_{yy} = 0,$$

where $k(0) = 0$, $k'(y) > 0$ for the first time posed a boundary value problem in which the carrier of the nonlocal boundary condition (“shock”)

$$u(0, y) - u(0, -y) = f(y)$$

is part of the $-a < y < a$ boundary of the $x = 0$ domain, consisting of parts of the boundaries of the subdomains of ellipticity and hyperbolicity of the equation. Therefore, nonlocal boundary

conditions of this type, connecting the values of functions on the boundaries of domains of different types of equations, are called Frankl conditions. In the work [2] we studied a problem with the classical boundary condition $u|_{AA_0} = 0$, $u_y|_{A_0B_0} = 0$ and a nonlocal boundary condition $u(\theta(t)) = (1 + \alpha)u(\theta_0(t)) + (1 - \alpha)u(\theta_1(t))$, $0 \leq t \leq 1$ for an inhomogeneous equation of parabolic-hyperbolic type. Also in the work [2] the statement of the problem, the hyperbolic part of the domain coincides with the characteristic triangle.

Theorem 2.1. Let $a = 0$, $b \neq 0$. If the conditions are met

$$\varphi^{(V)}(x) \in L_2[0, 1], \quad \varphi(0) = \varphi(1) = \varphi''(0) = \varphi''(1) = \varphi^{(IV)}(0) = \varphi^{(IV)}(1) = 0,$$

then there is a unique solution to the problem (2) - (6) and it is determined by the series

$$u(x, t) = \sum_{k=1}^{\infty} u_k(t) v_k(x) = \sqrt{2} \sum_{k=1}^{\infty} u_k(t) \sin \pi k x, \quad t > 0. \quad (7)$$

Theorem 2.2. Let $a = 0$, $b \neq 0$. Then to solve the problem (2) - (6) the estimates

$$\|u(x, t)\|^2 \leq C \|\varphi^{(IV)}(x)\|^2 \quad (8)$$

and

$$|u(x, t)| \leq C \|\varphi'''(x)\|, \quad (9)$$

are valid.

Theorem 2.3. Let $a \neq 0$, $b = 0$. Then if there is a solution to the problem (2)-(6), then it is unique if and only if $\Delta_\alpha(k) \neq 0$, which is for all $k \in \mathbb{N}$.

Theorem 2.4. Let $a \neq 0$, $b = 0$ and α be a positive rational number. Then if the conditions are met

$$\varphi^{(V)}(x) \in L_2[0, 1], \quad \varphi(0) = \varphi(1) = 0, \quad \varphi''(0) = \varphi''(1) = 0,$$

then there is a unique solution to the problem (2) - (6) and it is determined by the series

$$u(x, t) = \sum_{k=1}^{\infty} u_k(t) v_k(x) = \sqrt{2} \sum_{k=1}^{\infty} u_k(t) \sin \pi k x. \quad (10)$$

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VEYERSHTRAS FAKTORIZATSIYA TEOREMASI VA UNING TADBIQLARI

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Annotatsiya. Veyershtas faktorizatsiya teoremasi kompleks analizdagi fundamental natijalardan biri bo'lib, butun funksiyalarni ularning nollari orqali cheksiz ko'paytma shaklida ifodalash imkonini beradi. Ushbu ishda teorema bayoni, elementar omillar tushuntiriladi, $\sin(\pi\alpha)$, $\cos(\pi\alpha)$ va Gamma funksiyasi misollarida qo'llanilishi ko'rsatiladi hamda Hadamard refinement natijasi keltiriladi.

Kalit so'zlar. Butun funksiya, Veyershtas teoremasi, faktorizatsiya, elementar omillar, Gamma funksiya, kompleks analiz.

Kirish. Kompleks analizning markaziy muammolaridan biri bu butun funksiyalarni ularning nollari (ya'ni funksiya qiymati nolga aylanadigan nuqtalar) orqali tavsiflashdir. Oddiy ko'phadlar chekli ko'paytma shaklida yozilganidek, cheksiz ko'p nolga ega butun funksiyalar uchun ham shunday ifoda mavjudmi? Karl Veyershtas 1876 yilda ushbu savolga ijobiy javob berib, butun funksiyalarni cheksiz ko'paytma ko'rinishida yozish imkonini beruvchi faktorizatsiya teoremasini isbotladi.

Ta'rif. Agar $f(z)$ funksiya butun C da analitik bo'lsa, u holda $f(z)$ ga butun funksiya deyiladi. Veyershtas teoremasi butun funksiyalarni ularning nollari $a_1, a_2, a_3, \dots$ (ko'pligi hisobga

olingan holda) bo'yicha qurish imkonini beradi. Nollar cheksiz ko'p bo'lganda oddiy $\prod \left(1 - \frac{z}{a_n}\right)$ ko'paytma uzoqlashishi mumkin, shuning uchun maxsus tuzatuvchi ko'paytuvchilar kiritiladi.

Veyershtas faktORIZatsiya teoremasi

Teorema (Veyershtas, 1876). $f(z)$ butun funksiyaning $z = 0$ da m tartibli noli va boshqa $a_1, a_2, a_3, \dots$ nollari bo'lsin. U holda

$$f(z) = z^m e^{g(z)} \prod_{n=1}^{\infty} E_{p_n} \left(\frac{z}{a_n} \right)$$

ko'rinishida yoziladi, bunda $g(z)$ bu biror butun funksiya, va $E_p(u)$ Veyershtas elementar omili.

Elementar omillar $E_p(u)$

$$p=0 \text{ holatda, } E_0(u) = 1 - u$$

$$p=1 \text{ holatda, } E_1(u) = (1 - u)e^u$$

$$\text{Umumiy holatda, } E_p(u) = (1 - u)e^{\left(u + \frac{u^2}{2} + \dots + \frac{u^p}{p}\right)}$$

1-misol. $\sin(\pi z)$ funksiya sinind nollari $z = 0, \pm 1, \pm 2, \dots$ da joylashgan. Veyershtas teoremasiga asosan:

$$\sin(\pi z) = \pi z \prod_{n=1}^{\infty} \left(1 - \frac{z^2}{n^2}\right)$$

Bu formula Eyler tomonidan topilgan bo'lib Veyershtas teoremasi uni qat'iy asoslaydi. $\pm n$ nollari juftlab birlashtirilgan.

2-misol. $\cos(\pi z)$ ning nollari $z = \pm \frac{1}{2}, \pm \frac{3}{2}, \pm \frac{5}{2}, \dots$:

$$\cos(\pi z) = \prod_{n=1}^{\infty} \left(1 - \frac{4z^2}{(2n-1)^2}\right)$$

3-misol. Gamma funksiyaning teskarisi butun funksiya bo'lib, uning nollari $z = 0, -1, -2, \dots$:

$$\frac{1}{\Gamma(z)} = ze^{\gamma z} \prod_{n=1}^{\infty} \left(1 + \frac{z}{n}\right) e^{-\frac{z}{n}}$$

Bu yerda $\gamma \approx 0.5772$ bu Eyler konstantasi.

Hadamard refinement

Agar $f(z)$ sonli tartibli (ρ) butun funksiya bo'lsa, Hadamard teoremasi bo'yicha $g(z) - (\rho)$ darajali ko'phadmas bo'ladi, ya'ni:

$$f(z) = z^m e^{P(z)} \prod_{n=1}^{\infty} E_p \left(\frac{z}{a_n} \right)$$

bu yerda $p \leq (\rho)$. Bu Veyershtas teoremasini aniqlashtiradi.

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ON DYNAMICS OF A SEPARABLE CUBIC STOCHASTIC OPERATORS IN S^2

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Let $E = \{1, \dots, m\}$ be a finite set and the set of all probability distributions on E

$$S^{m-1} = \{x = (x_1, x_2, \dots, x_m) \in \mathbb{R}^m : x_i \geq 0, \text{ for any } i \text{ and } \sum_{i=1}^m x_i = 1\},$$

the $(m - 1)$ -dimensional simplex.

A cubic stochastic operator (CSO) is a mapping $W : S^{m-1} \rightarrow S^{m-1}$ of the form

$$W : x' = \sum_{i,j,k \in E} P_{ijk,l} x_i x_j x_k; \quad l \in E \quad (1)$$

where $P_{ijk,l}$ are the coefficients of heredity such that

$$P_{ijk,l} \geq 0, \forall i, j, k, l \in E, \quad \sum_{l \in E} P_{ijk,l} = 1, \forall i, j, k \in E, \quad (2)$$

that is, the coefficients $P_{ijk,l}$ do not change for any permutation of i, j and k if the types are not related to sex.

Let

$$A = (a_{il})_{i,l=1}^m, \quad B = (b_{jl})_{j,l=1}^m, \quad C = (c_{kl})_{k,l=1}^m$$

be the matrices with the real entries.

Consider a CSO (1), (2) with additional condition

$$P_{ijk,l} = a_{il} b_{jl} c_{kl} \quad \text{for all } i, j, k, l \in E, \quad (3)$$

where $a_{il}, b_{jl}, c_{kl} \in \mathbb{R}$ entries of matrices A, B and C such that the conditions (2) are satisfied for the coefficients (3). Then the CSO W corresponding to the coefficients (3) has the form

$$x'_l = (W(x))_l = (A(x))_l \cdot (B(x))_l \cdot (C(x))_l, \quad l \in E, \quad (4)$$

where $(A(x))_l = \sum_{i=1}^m a_{il} x_i$, $(B(x))_l = \sum_{j=1}^m b_{jl} x_j$ and $(C(x))_l = \sum_{k=1}^m c_{kl} x_k$.

Definition 1. The CSO (4) is called separable cubic stochastic operator (SCSO).

Let us consider the following matrices:

$$A = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, B = \begin{pmatrix} 1 & 1+a & 1 \\ 1-a & 1 & 1 \\ 1-b & 1 & 1 \end{pmatrix}, C = \begin{pmatrix} 1 & 1 & 1+b \\ 1 & 1 & 1+c \\ 1 & 1-c & 1 \end{pmatrix} \quad (5)$$

where $ab + bc + ac = 0$ and $a, b, c \in [-1, 1]$.

Then corresponding SCSO $W : S^2 \rightarrow S^2$ is:

$$W : \begin{cases} x_1' = x_1(x_1 + (1+a)x_2 + x_3)(x_1 + x_2 + (1+b)x_3), \\ x_2' = x_2((1-a)x_1 + x_2 + x_3)(x_1 + x_2 + (1+c)x_3), \\ x_3' = x_3((1-b)x_1 + x_2 + x_3)(x_1 + (1-c)x_2 + x_3), \end{cases} \quad (6)$$

Using the equation $x_1 + x_2 + x_3 = 1$ we rewrite the operator (6) as follows

$$W : \begin{cases} x_1' = x_1(1 + ax_2)(1 + bx_3), \\ x_2' = x_2(1 - ax_1)(1 + cx_3), \\ x_3' = x_3(1 - bx_1)(1 - cx_2), \end{cases} \quad (7)$$

Let a face of the simplex S^2 be the set $\Gamma_a = \{x \in S^2 : x_i = 0, i \notin \alpha \subset \{1, 2, 3\}\}$ Let the set $\text{int } S^2 = \{x \in S^2 : x_1 x_2 x_3 > 0\}$ and let the set $\partial S^2 = S^2 / \text{int } S^2$ be the interior and the

boundary of the simplex S^2 , respectively. Let $e_1 = (1, 0, 0)$, $e_2 = (0, 1, 0)$, $e_3 = (0, 0, 1)$ be the vertexes of the two-dimensional simplex.

Theorem 1. For the SCSO $W(7)$, the following assertions are true:

(i) The faces $\Gamma_{\{1,2\}}, \Gamma_{\{1,3\}}, \Gamma_{\{2,3\}}$ of the simplex S^2 are invariant sets;

(ii) The fixed points set is $\text{Fix}(W) = \{e_1, e_2, e_3\}$;

(iii) for any $x^{(0)} \in \Gamma_{\{1,2\}}$ we have

$$\omega_w(x^{(0)}) = \begin{cases} e_1, & \text{if } 0 < a \leq 1, \\ e_2, & \text{if } -1 \leq a < 0 \end{cases}$$

(iv) for any $x^{(0)} \in \Gamma_{\{1,3\}}$ we have

$$\omega_w(x^{(0)}) = \begin{cases} e_1, & \text{if } 0 < b \leq 1, \\ e_3, & \text{if } -1 \leq b < 0 \end{cases}$$

(v) for any $x^{(0)} \in \Gamma_{\{2,3\}}$

$$\omega_w(x^{(0)}) = \begin{cases} e_2, & \text{if } 0 < c \leq 1, \\ e_3, & \text{if } -1 \leq c < 0 \end{cases}$$

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ON DYNAMICS OF A QUADRATIC STOCHASTIC OPERATOR

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Let

$$S^2 = \{(x_1, x_2, x_3) \in R^3 : x_1 + x_2 + x_3 = 1, x_i \geq 0\},$$

be the two-dimensional simplex.

Consider the following quadratic operator:

$$W : \begin{cases} x'_1 = (1 - 2x_1 - 2x_2)(1 - 2x_1 - x_3), \\ x'_2 = (1 - 2x_3 - x_2)(1 - 2x_3 - x_1), \\ x'_3 = (1 + x_2 - x_3)(1 - x_1 + x_3). \end{cases} \quad (1)$$

Definition. A quadratic stochastic operator is generally defined as:

$$V(x)_k = \sum_{i,j=1}^m P_{ij,k} x_i x_j,$$

where, $P_{ij,k} \geq 0, \sum_{k=1}^m P_{ij,k} = 1, x = (x_1, x_2, \dots, x_m)$

Theorem 1. For the QSO $W(1)$, the following assertions true:

1. The faces $\Gamma_{1,2}$ of the simplex S^2 are invariant sets;

$$2. \quad Fix(W) = \left\{ e_1 = (1, 0, 0), \left(\frac{2}{3} - \frac{1}{\sqrt{3}}, \frac{1}{\sqrt{3}} - \frac{1}{3}, \frac{2}{3} \right) \right\}$$

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ON DYNAMICS OF A SEPARABLE CUBIC STOCHASTIC OPERATOR IN A TWO-DIMENSIONAL SIMPLEX

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Let $E = \{1, \dots, m\}$ be a finite set and the set of all probability distributions on E

$$S^{m-1} = \{x = (x_1, x_2, \dots, x_m) \in \mathbb{R}^m : x_i \geq 0, \text{ for any } i \text{ and } \sum_{i=1}^m x_i = 1\},$$

the $(m - 1)$ -dimensional simplex.

A cubic stochastic operator (CSO) is a mapping $W : S^{m-1} \rightarrow S^{m-1}$ of the form

$$W : x'_l = \sum_{i,j,k \in E} P_{ijk,l} x_i x_j x_k; \quad l \in E \quad (1)$$

where $P_{ijk,l}$ are the coefficients of heredity such that

$$P_{ijk,l} \geq 0, \forall i, j, k, l \in E, \sum_{l \in E} P_{ijk,l} = 1, \forall i, j, k \in E, \quad (2)$$

that is, the coefficients $P_{ijk,l}$ do not change for any permutation of i, j and k if the types are not related to sex.

Let

$$A = (a_{il})_{i,l=1}^m, \quad B = (b_{jl})_{j,l=1}^m, \quad C = (c_{kl})_{k,l=1}^m$$

be the matrices with the real entries.

Consider a CSO (1), (2) with additional condition

$$P_{ijk,l} = a_{il} b_{jl} c_{kl} \quad \text{for all } i, j, k, l \in E, \quad (3)$$

where $a_{il}, b_{jl}, c_{kl} \in R$ entries of matrices A, B and C such that the conditions (2) are satisfied for the coefficients (3). Then the CSO W corresponding to the coefficients (3) has the form

$$x'_l = (W(x))_l = (A(x))_l \cdot (B(x))_l \cdot (C(x))_l, \quad l \in E, \quad (4)$$

Where $(A(x))_l = \sum_{i=1}^m a_{il} x_i$, $(B(x))_l = \sum_{j=1}^m b_{jl} x_j$ and $(C(x))_l = \sum_{k=1}^m c_{kl} x_k$.

Definition1. The CSO (4) is called separable cubic stochastic operator (SCSO).

Let us consider the following matrices:

$$A = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, B = \begin{pmatrix} 1 & 1+a & 1 \\ 1-a & 1 & 1 \\ 1-b & 1 & 1 \end{pmatrix}, C = \begin{pmatrix} 1 & 1 & 1+b \\ 1 & 1 & 1+c \\ 1 & 1-c & 1 \end{pmatrix}$$

where $ab + bc + ac = 0$ and $a, b, c \in [-1, 1]$.

Then corresponding SCSO $W : S^2 \rightarrow S^2$ is:

$$W : \begin{cases} x_1 = x_1(x_1 + (1+a)x_2 + x_3)(x_1 + x_2 + (1-b)x_3), \\ x_2 = x_2((1-a)x_1 + x_2 + x_3)(x_1 + x_2 + (1+c)x_3), \\ x_3 = x_3((1+b)x_1 + x_2 + x_3)(x_1 + (1-c)x_2 + x_3). \end{cases} \quad (6)$$

Using the equation $x_1 + x_2 + x_3 = 1$ and

$$a = 1, b = 1, c = -0.5$$

we rewrite the operator (6) as follows

$$W : \begin{cases} x_1 = x_1(1 + x_2)(1 - x_3), \\ x_2 = x_2(1 - x_1)(1 - 0.5x_3), \\ x_3 = x_3(1 + x_1)(1 + 0.5x_2), \end{cases} \quad (7)$$

Let a face of the simplex S^2 be the set $\Gamma_\alpha = \{x \in S^2 : x_i = 0, i \notin \alpha \subset \{1, 2, 3\}\}$. Let the set $\text{int } S^2 = \{x \in S^2 : x_1 x_2 x_3 > 0\}$ and let the set $\partial S^2 = S^2 / \text{int } S^2$ be the interior and the boundary of the simplex S^2 , respectively. Let $e_1 = (1, 0, 0)$, $e_2 = (0, 1, 0)$, $e_3 = (0, 0, 1)$ be the vertexes of the two-dimensional simplex.

Theorem 1. For the SCSO W (7), the following assertions are true:

(i) The faces $\Gamma_{\{1,2\}}, \Gamma_{\{1,3\}}, \Gamma_{\{2,3\}}$ of the simplex S^2 are invariant sets;

(ii) The fixed points set is $\text{Fix}(W) = \{e_1, e_2, e_3\}$;

(iii) for any $x^{(0)} \in \Gamma\{1, 2\}$ we have

$$\omega_w(x^{(0)}) = e_1$$

(iv) for any $x^{(0)} \in \Gamma\{1, 3\}$ we have

$$\omega_w(x^{(0)}) = e_3$$

(v) for any $x^{(0)} \in \Gamma\{2, 3\}$

$$\omega_w(x^{(0)}) = e_3$$

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EMBEDDED EIGENVALUES OF THE DISCRETE SCHRÖDINGER OPERATOR ON THE LADDER OF ONE-DIMENSIONAL SQUARE LATTICE

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Abstract. We consider a discrete Schrödinger operator H on a ladder of one-dimensional

square lattices with a self-adjoint matrix-valued potential whose entries are $\lambda \cos(x-s)$ and $\mu \cos(x-s)$. We investigate conditions for the existence of eigenvalues and describe their exact locations in terms of the parameters λ and μ .

Let $L_2(\mathbb{T})$ be the Hilbert space of square-integrable functions defined on $\mathbb{T} = (-\pi, \pi]$ and $L_2^{(2)}(\mathbb{T})$ denote the Cartesian product of two copies of $L_2(\mathbb{T})$. We denote by $\sigma(A)$, $\sigma_{ess}(H)$ and $\sigma_p(A)$ respectively spectrum, essential spectrum and point spectrum of an operator A .

We consider the operator matrix H acting in the Hilbert space $L_2^{(2)}(\mathbb{T})$ as

$$H = H_0 - V,$$

where H_0 is a multiplication operator by matrix

$$H_0(x) = \frac{-1}{3} \begin{pmatrix} 2\cos x & 1 \\ 1 & 2\cos x \end{pmatrix}$$

and V is an operator matrix

$$V = \begin{pmatrix} \lambda \mathbf{v} & \mu \mathbf{v} \\ \mu \mathbf{v} & \lambda \mathbf{v} \end{pmatrix}$$

with the integral operator

$$\mathbf{v}f = \int_{\mathbb{T}} \cos(x-s)f(s)ds, \quad f \in L_2(\mathbb{T}).$$

The spectrum $\sigma(H_0)$ of the operator H_0 [1] is $\sigma(H_0) = [-1, 1]$.

Because V is a compact operator, Weyl's theorem for the essential spectrum [2] yields

$$\sigma_{ess}(H) = \sigma(H_0).$$

Let $\tilde{H} = \begin{pmatrix} H_1 & 0 \\ 0 & H_2 \end{pmatrix}$, where $H_1 = H_{10} - (\lambda + \mu)\mathbf{v}$, $H_2 = H_{20} - (\lambda - \mu)\mathbf{v}$,

H_{10} and H_{20} are multiplication operators on $L_2(\mathbb{T})$ by functions

$$E_{10}(x) = -\frac{2}{3}\cos x - \frac{1}{3} \quad \text{and} \quad E_{20}(x) = -\frac{2}{3}\cos x + \frac{1}{3},$$

respectively.

Lemma 2.1 *The operator $\tilde{H}$ is unitarily equivalent to the operator H .*

Since the operators H and $\tilde{H}$ are unitarily equivalent, an investigation eigenvalue problem for H reduces to study eigenvalue problems for H_1 and H_2 , since $\sigma(H) = \sigma(H_1) \cup \sigma(H_2)$.

The Weyl theorem for the essential spectrum [11] implies that $\sigma_{ess}(H_1)$ and $\sigma_{ess}(H_2)$ coincide with the range of the functions E_{10} and E_{20} , respectively, i.e.

$$\sigma_{ess}(H_1) = [-1, \frac{1}{3}] \quad \text{and} \quad \sigma_{ess}(H_2) = [-\frac{1}{3}, 1].$$

This lemma allows to describe the location of the eigenvalues of the operator H_α with respect to the parameters λ and μ .

Lemma 2.3 *For any $\lambda + \mu \neq 0$, the operator H_1 has two eigenvalues z_1 and z_2 lying on $\mathbb{R} \setminus [-1, \frac{1}{3}]$ and H_1 has no any eigenvalue for $\lambda = -\mu$. Moreover,*

(1) If $\lambda + \mu > 0$, then $z_1, z_2 \in (-\infty, -1)$;

(2) If $\lambda + \mu < 0$, then $z_1, z_2 \in (\frac{1}{3}, \infty)$. More precisely,

(i) If $\frac{1}{\pi(6-4\sqrt{3})} < \lambda + \mu < 0$, then $z_1, z_2 \in (\frac{1}{3}, 1)$. Moreover, in this case the eigenvalues z_1, z_2 of H_1 lie in the essential spectrum $\sigma_{ess}(H_2)$;

(ii) If $\lambda + \mu = \frac{1}{\pi(6-4\sqrt{3})}$, then $z_1 = 1$ and $z_2 \in (\frac{1}{3}, 1)$;

(iii) If $\frac{1}{\pi(3\sqrt{3}-6)} < \lambda + \mu < \frac{1}{\pi(6-4\sqrt{3})}$, then $z_1 \in (1, \infty)$ and $z_2 \in (\frac{1}{3}, 1)$;

(iv) If $\lambda + \mu = \frac{1}{\pi(3\sqrt{3}-6)}$, then $z_1 \in (1, \infty)$ and $z_2 = 1$;

(v) If $\lambda + \mu < \frac{1}{\pi(3\sqrt{3}-6)}$, then $z_1, z_2 \in (1, \infty)$.

Lemma 2.4 For any $\lambda - \mu \neq 0$, the operator H_2 has two eigenvalues z_3, z_4 lying on $\mathbb{R} \setminus [-\frac{1}{3}, 1]$ and H_2 has no any eigenvalue for $\lambda = \mu$. Moreover,

(1) If $\lambda - \mu < 0$, then $z_3, z_4 \in (1, \infty)$;

(2) If $\lambda - \mu > 0$, then $z_3, z_4 \in (-1, \infty)$. More precisely,

(i) If $0 < \lambda - \mu < \frac{1}{\pi(4\sqrt{3}-6)}$, then $z_3, z_4 \in (-1, -\frac{1}{3})$. Moreover, in this case z_3, z_4 lie in the essential spectrum $\sigma_{ess}(H_1)$;

(ii) If $\lambda - \mu = \frac{1}{\pi(4\sqrt{3}-6)}$, then $z_3 = -1$ and $z_4 \in (-1, -\frac{1}{3})$;

(iii) If $\frac{1}{\pi(4\sqrt{3}-6)} < \lambda - \mu < \frac{1}{\pi(6-3\sqrt{3})}$, then $z_3 \in (-\infty, -1)$ and $z_4 \in (-1, -\frac{1}{3})$;

(iv) If $\lambda - \mu = \frac{1}{\pi(6-3\sqrt{3})}$, then $z_3 \in (-\infty, -1)$ and $z_4 = -1$;

(v) If $\lambda - \mu > \frac{1}{\pi(6-3\sqrt{3})}$, then $z_3, z_4 \in (-\infty, -1)$.

We introduce the following sets:

$$I_1 = \{(\lambda, \mu) : \lambda + \mu = 0\}, I_2 = \{(\lambda, \mu) : \lambda - \mu = 0\},$$

$$D_1 = \{(\lambda, \mu) : 1/\pi(6-4\sqrt{3}) \leq \lambda + \mu < 0\}, D_2 = \{(\lambda, \mu) : 1/\pi(3\sqrt{3}-6) \leq \lambda + \mu < 1/\pi(6-4\sqrt{3})\},$$

$$D_3 = \{(\lambda, \mu) : 0 < \lambda - \mu \leq 1/\pi(4\sqrt{3}-6)\}, D_4 = \{(\lambda, \mu) : 1/\pi(4\sqrt{3}-6) < \lambda - \mu < 1/\pi(6-3\sqrt{3})\}.$$

Combining Lemma 2.3 and Lemma 2.4 we immediately obtain the following theorem.

Theorem 2.5

1. For $(\lambda, \mu) \in \mathbb{R}^2 \setminus (I_1 \cup I_2)$ the operator H has four eigenvalues. Moreover,
 1. if $(\lambda, \mu) \in (D_1 \cap D_3)$, then all of the eigenvalues of the operator H are in $\sigma_{ess}(H)$;
 2. if $(\lambda, \mu) \in (D_2 \cap D_3) \cup (D_1 \cap D_4)$, then three of the eigenvalues of the operator H are in $\sigma_{ess}(H)$;
 3. if $(\lambda, \mu) \in D_3 \setminus (D_1 \cup D_2) \cup D_1 \setminus (D_3 \cup D_4) \cup (D_2 \cap D_4)$, then two of the eigenvalues of the operator H are in $\sigma_{ess}(H)$;
 4. if $(\lambda, \mu) \in D_4 \setminus (D_1 \cup D_2) \cup D_2 \setminus (D_3 \cup D_4)$, then only one of the eigenvalues of the operator H is in $\sigma_{ess}(H)$.

2. For $(\lambda, \mu) \in (l_1 \cup l_2) \setminus (0, 0)$ the operator H has two eigenvalues. Moreover,
1. if $(\lambda, \mu) \in (D_1 \cap l_2) \cup (D_3 \cap l_1)$, then both of the eigenvalues of the operator H are in $\sigma_{ess}(H)$;
2. if $(\lambda, \mu) \in (D_2 \cap l_2) \cup (D_4 \cap l_1)$, then only one of the eigenvalues of the operator H is in $\sigma_{ess}(H)$.

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IZOSPEKTRAL SHTURM-LIUUVILL OPERATORLARI

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Annotatsiya. Ushbu maqolada spektrlari bir xil bo'lgan har xil Shturm – Liuvill chegaraviy masalalari oilasini qurish algoritmi bayon qilingan.

Kalit so'zlar: xos qiymat, normallovchi o'zgarmlar, integral tenglama.

Kirish

1-ta'rif. Ushbu

$$L^0 y \equiv -y'' + q_0(x)y = \lambda y, \quad y(0) = 0, y(\pi) = 0, \quad (0 < x < \pi) \quad (a)$$

va

$$Ly \equiv -y'' + q(x)y = \lambda y, \quad y(0) = 0, y(\pi) = 0, \quad (0 < x < \pi) \quad (b)$$

Shturm-Liuvill chagaraviy masalalari bir xil xos qiymatlarga ega bo'lsa, ya'ni $\sigma(L^0) = \sigma(L) = \{\lambda_n = \lambda_n^0, n \geq 0\}$ tenglik o'rinli bo'lsa (a) va (b) masalalarga izospektral chegaraviy masalalar deyiladi.

Teskari spektral masalalarga oid zaruriy ma'lumotlar

Ushbu

$$Ly \equiv -y'' + q(x)y = \lambda y, \quad (0 < x < \pi), \quad (1)$$

Shturm-Liuvill tenglamasini quyidagi chegaraviy shartlar bilan qaraymiz:

$$y(0) = 0, \quad y(\pi) = 0. \quad (2)$$

Bunda $q(x) \in C[0, \pi]$ – haqiqiy uzluksiz funksiya, λ – kompleks parametr. (1) tenglamaning quyidagi

$$\psi(0, \lambda) = 0, \quad \psi'(\pi, \lambda) = 1 \quad (3)$$

boshlang'ich shartlarni qanoatlantiruvchi yechimini $\psi(x, \lambda)$ orqali belgilaymiz.

Ma'lumki [1], (1) va (3) Koshi masalasining $\psi(x, \lambda)$ yechimi mavjud, yagona va har bir fiksirlangan $x \in [0, \pi]$ da λ bo'yicha butun funksiya bo'ladi. Shuningdek, ushbu integral tasvir o'rinli:

$$\psi(x, \lambda) = \frac{\sin \sqrt{\lambda} x}{\sqrt{\lambda}} + \frac{1}{\sqrt{\lambda}} \int_0^x G(x, t) \sin \sqrt{\lambda} t \, dt, \quad (4)$$

$$G(x, x) = \frac{1}{2} \int_0^x q(t) \, dt.$$

Ko'rinib turibdiki, $\psi(x, \lambda)$ funksiyalar barcha λ larda $y(0) = 0$, chegaraviy shartni qanoatlantiradi. Shuning uchun $L(q(x), \infty, \infty)$ chegaraviy masalalarning $\tilde{\mu}_n$ xos qiymatlari ushbu

$$\tilde{\delta}(\lambda) \equiv \psi(\pi, \lambda) = 0$$

tenglamaning ildizlaridan iborat bo‘ladi. Ushbu $\psi(x, \tilde{\mu}_n)$ funksiyalar esa ularga mos keluvchi xos funksiyalardir.

Quyidagi

$$\tilde{\delta}_n = \int_0^\pi \psi^2(x, \tilde{\mu}_n) dx,$$

sonlarga $L(q(x), \infty, \infty)$ chegaraviy masalaning normallovchi o‘zgarmaslari deb ataladi.

1-ta’rif. Ushbu $\{\tilde{\mu}_n, \tilde{\delta}_n\}_{n=1}^\infty$ ketma-ketliklar juftliklariga $L(q(x), \infty, \infty)$ chegaraviy masalalarning spektral berilganlari deyiladi.

2-ta’rif. $\{\tilde{\mu}_n, \tilde{\delta}_n\}_{n=1}^\infty$ spektral berilganlar yordamida $L(q(x), \infty, \infty)$ chegaraviy masalaning $q(x)$ potentsiali topish masalasiga teskari spektral masala deyiladi.

1-teorema [2]. $\{\tilde{\mu}_n, \tilde{\delta}_n; \tilde{\delta}_n > 0\}_{n=1}^\infty$ haqiqiy sonlar ketma-ketliklari $L(q(x), \infty, \infty)$ Shturm-Liuvill chegaraviy masalalarining spektral berilganlari bo‘lishi uchun quyidagi

$$\sqrt{\tilde{\mu}_n} = n + \frac{\tilde{d}}{n\pi} + \frac{\tilde{\omega}_n}{n}, \quad \{\tilde{\omega}_n\} \in l_2, \quad \tilde{\mu}_n \neq \tilde{\mu}_m, \quad n \neq m,$$

$$\tilde{\delta}_n = \frac{\pi}{2n^2} + \frac{\tilde{\sigma}_n}{n^3}, \quad \tilde{\delta}_n > 0, \quad \{\tilde{\sigma}_n\} \in l_2, \quad \tilde{d} = \frac{1}{2} \int_0^\pi q(t) dt \quad (5)$$

tengliklarning bajarilishi zarur va yetarli.

Ma’lumki, (5) integral tasvirlardagi $G(x, t)$ funksiyalar mos ravishda quyidagi

$$G(x, t) + \tilde{F}(x, t) + \int_0^x G(x, s) \tilde{F}(s, t) ds = 0, \quad (0 < t < x), \quad (6)$$

Gelfand-Levitan integral tenglamalarini qanoatlantiradi. Bunda

$$\tilde{F}(x, t) = \sum_{n=1}^\infty \left\{ \frac{1}{\tilde{\delta}_n} \frac{\sin \sqrt{\tilde{\mu}_n} x \sin \sqrt{\tilde{\mu}_n} t}{\tilde{\mu}_n} - \frac{2}{\pi} \sin nx \sin nt \right\}. \quad (7)$$

Aytaylik, (5) shartlarni qanoatlantiruvchi $\{\tilde{\mu}_n, \tilde{\delta}_n; \tilde{\delta}_n > 0\}_{n=1}^\infty$ haqiqiy sonlar ketma-ketliklari berilgan bo‘lsin. U holda (7) formuladan foydalanib, $\tilde{F}(x, t)$ funksiyani tuzib olamiz. Uni (6) Gelfand-Levitan integral tenglamasiga qo‘yib, $G(x, t)$ noma’lumni topib olamiz. Ushbu

$$q(x) = 2 \frac{d}{dx} G(x, x)$$

tengliklar yordamida $L(q(x), \infty, \infty)$ Shturm-Liuvill chegaraviy masalasining barcha koeffitsiyentlarini topib olamiz.

Izospektral chegaraviy masalalarni tiklash algoritmi

2-teorema. Aytaylik, $\{\tilde{\mu}_n, \tilde{\delta}_n\}_{n=1}^\infty$ haqiqiy sonlardan tuzilgan ketma-ketliklar juftligi quyidagi shartlarni qanoatlantirsin

$$\sqrt{\tilde{\mu}_n} = n, \quad n \geq 1; \quad \frac{1}{\tilde{\delta}_n} = \frac{1}{\tilde{\delta}_n^0} + \frac{\tilde{\tau}_n}{n}, \quad \tilde{\tau}_n > 0, \quad \sum_{n=1}^\infty \tilde{\tau}_n^2 < \infty, \quad \tilde{\delta}_n^0 = \frac{\pi}{2n^2}, \quad n \geq 1. \quad (8)$$

U holda bu juftlik $L(q(x, \tilde{\tau}_1, \tilde{\tau}_2, \dots, \tilde{\tau}_n, \dots), \infty, \infty)$ ko‘rinishdagi biror Shturm-Liuvill chegaraviy masalasining spektral berilganlari bo‘ladi.

Ushbu $L(q(x, \tilde{\tau}_1, \tilde{\tau}_2, \dots, \tilde{\tau}_n, \dots), \infty, \infty) = L(\tilde{\tau}_1, \tilde{\tau}_2, \dots, \tilde{\tau}_n, \dots)$ chegaraviy masalaning $q(x, \tilde{\tau}_1, \tilde{\tau}_2, \dots, \tilde{\tau}_n, \dots)$ koeffitsiyentini topish uchun teskari spektral masalani yechishning Gelfand-Levitan usulidan foydalanamiz. U holda $q(x, \tilde{\tau}_1, \tilde{\tau}_2, \dots, \tilde{\tau}_n, \dots)$ funksiya quyidagicha aniqlanadi:

$$q(x, \tilde{\tau}_1, \tilde{\tau}_2, \dots, \tilde{\tau}_n, \dots) = - \sum_{n=1}^\infty \frac{\tilde{\tau}_n}{n^3} (\psi(x, \tilde{\mu}_n) \sin nx)'. \quad (9)$$

Bu yerda $\psi(x, \tilde{\mu}_n), n \geq 1$ funksiyalar quyidagi

$$\psi(x, \tilde{\mu}_n) = \sin nx - \sum_{k=1}^{\infty} \left\{ \frac{\tilde{\tau}_k}{k^3} \psi(x, \tilde{\mu}_k) \int_0^x \sin ns \sin ks ds \right\}, n \geq 1,$$

tenglamalar sistemasini qanoatlantiradi. Shunday qilib, $L(\tilde{\tau}_1, \tilde{\tau}_2, \dots, \tilde{\tau}_n, \dots)$ ko'rinishdagi izospektral Shturm-Liuvill chegaraviy masalalari oilasining barcha koeffitsiyentlarini topishga muvaffaq bo'ldik. Xususan, agar $\tilde{\tau}_1 > 0, \tilde{\tau}_n = 0, n \geq 2$ bo'lsa, u holda quyidagi izospektral chegaraviy masalaga ega bo'lamiz:

$$L(\tilde{\tau}_1)y \equiv -y'' + \frac{32\tilde{\tau}_1^2 \sin^4 x - 8\tilde{\tau}_1 \sin 2x(4 + \tilde{\tau}_1(2x - \sin 2x))}{(4 + \tilde{\tau}_1(2x - \sin 2x))^2} y = \lambda y, 0 < x < \pi, \quad (9)$$

$$y(0) = 0, \quad y(\pi) = 0. \quad (10)$$

(9)-(10) Shturm-Liuvill chegaraviy masalasining xos qiymatlari $\tilde{\mu}_n = n^2, n \geq 0$ ga teng bo'ladi. Endi (9)-(10) masalani to'g'ri usulda yechib xos qiymatlarini quyidagicha aniqlaymiz:

tau_1= 0.5			tau_1= 0.9			tau_1= 1.7		
n	lambda_n	xatolik	n	lambda_n	xatolik	n	lambda_n	xatolik
1	1.00000	6.0e-13	1	1.00000	1.5e-14	1	1.00000	4.8e-13
2	4.00000	5.0e-13	2	4.00000	8.5e-13	2	4.00000	8.9e-13
3	9.00000	1.4e-12	3	9.00000	3.4e-12	3	9.00000	3.6e-12
4	16.00000	5.9e-12	4	16.00000	7.3e-12	4	16.00000	4.7e-12
5	25.00000	3.4e-12	5	25.00000	8.9e-13	5	25.00000	2.1e-12
6	36.00000	1.4e-12	6	36.00000	2.6e-12	6	36.00000	1.4e-12
7	49.00000	5.0e-12	7	49.00000	3.8e-12	7	49.00000	4.3e-13
8	64.00000	1.2e-12	8	64.00000	2.4e-12	8	64.00000	2.5e-12
9	81.00000	3.3e-12	9	81.00000	7.1e-13	9	81.00000	2.7e-13
10	100.00000	1.3e-	10	100.00000	2.8e-14	10	100.00000	1.7e-13
12			11	121.00000	2.8e-12	11	121.00000	4.4e-13
11	121.00000	3.7e-	12	144.00000	9.4e-13	12	144.00000	2.5e-12
13			13	169.00000	5.1e-13	13	169.00000	5.0e-12
12	144.00000	5.7e-	14	196.00000	4.5e-13	14	196.00000	1.6e-12
14			15	225.00000	1.7e-13	15	225.00000	1.1e-13
13	169.00000	1.4e-	16	256.00000	2.8e-13	16	256.00000	5.7e-14
13			17	289.00000	4.0e-13	17	289.00000	4.0e-13
14	196.00000	2.8e-	18	324.00000	5.7e-14	18	324.00000	4.5e-13
14			19	361.00000	2.8e-13	19	361.00000	0.0e+00
15	225.00000	2.3e-	20	400.00000	5.7e-13	20	400.00000	4.0e-13
13								
16	256.00000	1.7e-						
13								
17	289.00000	2.3e-						
13								
18	324.00000	2.8e-						
13								
19	361.00000	2.8e-						
13								

20 13	400.00000	1.7e-		

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РАЗРЕШИМОСТЬ НЕЛОКАЛЬНЫХ ЗАДАЧ ДЛЯ СМЕШАННОГО ДИФФУЗИОННО-ВОЛНОВОГО УРАВНЕНИЯ ДРОБНОГО ПОРЯДКА

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Аннотация. Уравнение дробного порядка обобщает уравнение целочисленного порядка, а также сравнительно малое количество систематизированных аналитических и численных методов для таких уравнений, делают это направление приоритетным для общей теории дифференциальных уравнений.

Рассмотрим уравнение

$$Lz(x, y) = f(x, y) \quad (1)$$

где

$$Lz(x, y) = \begin{cases} {}_c D_{0x}^\alpha z(x, y) - z_{yy}(x, y), & (x, y) \in \Omega_0 \\ z_{xx}(x, y) - z_{yy}(x, y), & (x, y) \in \Omega_1 \end{cases}, \quad (2)$$

$${}_c D_{0x}^\alpha z(x, y) = \frac{1}{\Gamma(1-\alpha)} \int_0^x \frac{z_x(t, y)}{(x-t)^\alpha} dt, \quad 0 < \alpha < 1$$

$\Gamma(x)$ – гамма-функция Эйлера, (2) – интегро-дифференциальный оператор дробного порядка α в смысле Капуто [1, с.92], в области $\Omega = \Omega_0 \cup \Omega_1 \cup AB$.

Здесь Ω_0 -прямоугольник ABB_0A_0 с вершинами $A(0,0), B(1,0), B_0(1,1), A_0(0,1), \Omega_1$ – область, ограниченная отрезками AB и характеристиками $AC: x+y=0, BC: x-y=1$ уравнения (1), $f(x, y)$ -заданная функция.

Пусть гладкая кривая $AD: y = -\gamma(x), 0 < x < l$, где $0,5 < l \leq 1; \gamma(0) = 0, l + \gamma(l) = 1$, если $l < 1$ и $\gamma(l) = 0$, если $l = 1$ расположена внутри характеристического треугольника $0 < x + y \leq x - y < 1$.

Относительно кривой $\gamma(x)$, предположим, что $\gamma(x)$ – дважды непрерывно дифференцируемая функция и $x \pm \gamma(x)$ – монотонно возрастающие функции, причем $0 < \gamma'(x) < 1, \gamma(x) > 0, x > 0$.

Задача В. Найти решение уравнения (1), удовлетворяющее условиям:

$$z(0, y) = 0, 0 \leq y \leq 1, \quad (3)$$

$$z(x, 1) = 0, 0 \leq x \leq 1, \quad (4)$$

$$[z_x - z_y][\theta_0(t)] + \mu(t)[z_x - z_y][\theta^*(t)] = 0, 0 < t < 1, \quad (5)$$

где $\theta_0(t), (\theta^*(t))$ – аффикс точки пересечения характеристики AC (кривой AD) с характеристикой выходящей из точки $(t, 0), 0 < t < 1, \mu(t)$ – заданная функция.

В случае, когда $\alpha = 1$, задача $M_l B$ совпадает с нелокальной задачей для смешанного парабола-гиперболического уравнения с нехарактеристической линией изменения типа. В

этом случае, вопросы регулярной и сильный разрешимости, а также вольтерровость задачи B исследованы в [3], [5].

И доказываем следующую теорему

Теорема 1. Пусть $\mu(t) \in C^1[0,1]$ и $\mu(x) = -1, 0 \leq x \leq 1$. Тогда для любой функции $f(x, y) \in C^1(\bar{\Omega})$, $f(A) = 0$ существует единственное регулярное решение задачи B (1), (3)-(5) и оно представимо в виде

$$z(x, y) = \iint_{\Omega} M_1(x, y, x_1, y_1) f(x_1, y_1) dx dy, \quad (6)$$

$$M_1(x, y, x_1, y_1) = \theta(x - x_1) [\theta(y) M_{01}(x, y, x_1, y_1) + \theta(-y) M_{11}(x, y, x_1, y_1)] \quad \text{и}$$

удовлетворяет неравенству

$$\begin{aligned} D_{0x}^{\alpha-1} \|z(x, y)\|_{L_2(0,1)}^2 + \int_0^x \|z_y(t, y)\|_{L_2(0,1)}^2 dt + \|z(x, y)\|_{W_2^1(\Omega_2)}^2 \leq \\ \leq C \left[\int_0^x \|f(t, y)\|_{L_2(0,1)}^2 dt + \int_0^x d\xi \int_{\xi}^1 |f(\xi, x)|^2 dt + \|f(x, y)\|_{L_2(\Omega)}^2 \right] \end{aligned} \quad (7).$$

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ЗАДАЧИ С НАКЛОННОЙ ПРОИЗВОДНОЙ ДЛЯ СМЕШАННОГО ПАРАБОЛО-ГИПЕРБОЛИЧЕСКОГО УРАВНЕНИЯ.

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Аннотация. Основной целью настоящей работы является показать, что корректность задачи с наклонной производной, заданной на отходе от характеристики для смешанного парабола-гиперболического уравнения с характеристической линией изменения типа

Пусть $\Omega \subset R^2$ - конечная область, ограниченная при $y > 0$ отрезками AA_0 , A_0B_0 , BB_0 , $A(0,0)$, $A_0(0,1)$, $B(1,0)$, $B_0(1,1)$, а при $y < 0$ - гладкой кривой $AD: y = -\gamma(x)$, $0 \leq x \leq \ell$, где $0,5 < \ell \leq 1$, $\gamma(0) = 0$, $\ell + \gamma(\ell) = 1$, расположенной внутри характеристического треугольника $ABC: 0 \leq x + y < x - y \leq 1$, и отрезком характеристики $BC: x - y = 1$, $\ell \leq x \leq 1$, уравнения смешанного парабола-гиперболического типа

$$Lu = f(x, y), \quad (1) \quad \text{где}$$

$$Lu = \begin{cases} u_{xx} - u_y, & y > 0 \\ u_{xx} - u_{yy}, & y < 0. \end{cases}$$

Относительно кривой AD будем предполагать, что ни в одной своей точке она не имеет характеристического направления, принадлежит классу функций $C^1[0, \ell]$ и $\gamma(0) = 0$, $0 < x \leq \ell < 1$, $\ell + \gamma(\ell) = 1$, функция $x + \gamma(x)$ монотонно возрастает.

Задача БМ. Найти решение уравнения (1), удовлетворяющее условиям

$$u|_{AA_0 \cup BB_0} = 0, \quad (2)$$

$$[a(x, y)u_x + b(x, y)u_y + c(x, y)u]_{AD} = 0, \quad (3)$$

где $a(x, y)$, $b(x, y)$, $c(x, y)$ - заданные функции.

Для областей D, таких, что $\bar{D} \cap \{A\} \neq \emptyset$, определим функциональное пространство

$$C_{\alpha}^{m,n}(\bar{D}) = \left\{ u(x, y) : \frac{\partial^{i+j} u(x, y)}{\partial x^i \partial y^j} \in C(\bar{D}), \quad \frac{\partial^{i+j} u(0, 0)}{\partial x^i \partial y^j} = 0, \quad i + \frac{m}{n} j \leq m-1, \quad m \geq n \geq 0, \right.$$

$$\left. \frac{\partial^{i+j} u(x, y)}{\partial x^i \partial y^j} \in C(\bar{D} \setminus A), \quad i + \frac{m}{n} j = m, \quad \max_{i + \frac{m}{n} j = m} \sup_{x \in \bar{D}} \left| x^{-\alpha} \frac{\partial^{i+j} u(x, y)}{\partial x^i \partial y^j} \right| < \infty, \alpha \geq 0 \right\}.$$

Ясно, что относительно нормы $\|u\|_{m,n,\alpha} = \max_{i + \frac{m}{n} j = m} \sup_{(x,y) \in \bar{D}} \left| x^{-\alpha} \frac{\partial^{i+j} u(x, y)}{\partial x^i \partial y^j} \right|$ пространство $C_{\alpha}^{m,n}(\bar{D})$

является банаховым.

Аналогично определим пространство на отрезке $[0, 1]$:

$$C_{\alpha}^k[0, 1] = \left\{ \varphi(x) : \varphi^{(j)}(x) \in C[0, 1], \quad \varphi^{(j)}(0) = 0, \quad j = 0, 1, \dots, k-1, \quad \varphi^{(k)}(x) \in C(0, 1], \quad \sup_{0 \leq x \leq 1} x^{-\alpha} |\varphi^{(k)}(x)| < \infty \right\}$$

с нормой

$$\|\varphi(x)\|_{k,\alpha} = \sup_{0 \leq x \leq 1} \left| \frac{\varphi^{(k)}(x)}{x^{\alpha}} \right|, \quad k \geq 0, \alpha \geq 0. \text{ Пусть}$$

$$\Omega_0 = \Omega \cap \{y > 0\}, \quad \Omega_1 = \Omega \cap \{y < 0\}.$$

Под регулярным решением задачи БМ будем понимать ограниченную функцию из класса

$$C(\bar{\Omega} \setminus B) \cap C^1(\Omega \cup AD) \cap C^{2,1}(\Omega_0) \cap C^{2,2}(\Omega_1),$$

удовлетворяющую уравнению (1) в $\Omega_0 \cup \Omega_1$ и условиям (2) и (3).

Обозначим, как обычно,

$$\tau(x) = u(x, 0), \quad \nu(x) = u_y(x, 0). \quad (4)$$

В силу однозначной разрешимости первой начально-краевой задачи для уравнения теплопроводности любое регулярное решение уравнения (1) при $y > 0$, удовлетворяющее условиям (2) и $u|_{AB} = \tau(x)$, представимо в виде

$$u(x, y) = - \int_0^y \int_0^1 G(x, x_1, y - y_1) f(x_1, y_1) dx_1 dy_1 + \int_0^1 G(x, x_1, y) \tau(x_1) dx_1, \quad (5) \quad \text{где}$$

$G(x, x_1, y)$ - функция Грина первой краевой задачи для уравнения (1) в области Ω_0 :

$$G(x, x_1, y) = 2 \sum_{n=1}^{\infty} e^{-\pi^2 n^2 y} \cdot \text{Sinn} \pi \text{Sinn} \pi x_1$$

В области Ω_0 в уравнении (1), переходя к пределу при $y \rightarrow 0$, с учетом (4), получим

$$\tau''(x) - \nu(x) = f(x, 0), \quad 0 < x < 1. \quad (6)$$

Соотношение (6) является основным функциональным соотношением между $\tau(x)$ и $\nu(x)$, принесенным на отрезок AB из области Ω_0 .

Далее, в силу однозначной разрешимости задачи Коши для волнового уравнения любое регулярное решение уравнения (1) при $y < 0$ представимо в виде

$$u(\xi, \eta) = \frac{1}{2} \left[\tau(\xi) + \tau(\eta) - \int_{\xi}^{\eta} v(t) dt \right] - \int_{\xi}^{\eta} d\xi_1 \int_{\xi_1}^{\eta} f_1(\xi_1, \eta_1) d\xi_1 d\eta_1, \quad (7)$$

В формуле (7), удовлетворяя условию (3), имеем

$$[a(x) - b(x)] [\tau'(x) - v(x)] + [a(x) + b(x)] [\tau'(\lambda(x)) + v(\lambda(x))] + c(x) \left[\tau(x) + \tau(\lambda(x)) - \int_{\lambda(x)}^x v(t) dt \right] = F(x), \quad (8)$$

$$F(x) = 2c(x) \int_{\lambda(x)}^x d\xi_1 \int_{\xi_1}^x f_1(\xi_1, \eta_1) d\eta_1 + [a(x) - b(x)] \int_{\lambda(x)}^x f_1(\xi_1, x) d\xi_1 - [a(x) + b(x)] \int_{\lambda(x)}^x f_1(\lambda(x), \eta_1) d\eta_1. \quad (9)$$

Соотношение (8) является основным соотношением между $\tau(x)$ и $v(x)$, принесенным на отрезок АВ из области Ω_1 .

Т е о р е м а . Если $-\frac{\pi}{2} < \theta < 0$ или $\frac{\pi}{2} < \theta < \pi$, то для любой функции

$$f(x, y) \in C_{\alpha}^{0,0}(\overline{\Omega_0}) \cap C_{\alpha}^{1,1}(\overline{\Omega_1}) \cap C^{1,0}(\Omega_0)$$

существует единственное регулярное решение задачи БМ из класса

$$u(x, y) \in C^{1,1}(\overline{\Omega} \setminus B) \cap C_{\alpha}^{2,1}(\overline{\Omega_0} \setminus B) \cap C_{\alpha}^{2,2}(\overline{\Omega_1})$$

Если $0 < \theta < \frac{\pi}{2}$ или $\pi < \theta < \frac{3\pi}{2}$, то задача БМ в указанном классе является нормально

разрешимой по Хаусдорфу и ее индекс $\chi = +\infty$ и, в частности, соответствующая однородная задача имеет бесконечное множество линейно независимых решений.

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TOR TEBRANISH TENGLAMANI UCHUN INTEGRAL SHARTLI TESKARI MASALA

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Annotatsiya. Mazkur tezisda tor tebranish tenglamasi uchun integral shartli teskari masala o'rganilgan. Masalada ikki noma'lum funktsiyani aniqlash talab qilinib, ular giperbolik turdagi differensial tenglama, boshlang'ich va chegaraviy shartlar hamda qo'shimcha integral shart orqali izlanadi. Tadqiqotda berilgan shartlar asosida masalaning yechimini mavjudligi va yagonaligi isbotlangan. Shuningdek, noma'lum funktsiyalarning aniq analitik ifodalari olingan hamda ularning yechimni tiklashdagi ahamiyati ko'rsatilgan. Olingan natijalar matematik fizikaning teskari masalalari nazariyasini rivojlantirishda va tor tebranish jarayonlarini modellashtirishda muhim ahamiyatga ega.

$t=0, t=x$ va $t=1-x$ chiziqlar bilan chegaralangan sohani D bilan belgilaylik. D sohada ushbu

$$U_{tt} - U_{xx} = f(t) \quad (1)$$

tenglamani qaraylik, bu yerda $U(x, t)$, $f(t)$ -noma'lum funksiyalar.

T masala. $U(x, t) \in C(\bar{D})$, $U_{xx}, U_{tt} \in C(D)$, $f(t) \in C\left[0, \frac{1}{2}\right]$ sinfdagi, (1) tenglama va

$$U(x, 0) + \lambda \int_0^x U(\xi, 0) d\xi = a(x), \quad 0 \leq x \leq 1, \quad (2)$$

$$U_t(x, 0) = v(x), \quad 0 < x < 1, \quad (3)$$

integral va boshlang'ich hamda

$$U(t, t) = \varphi(t) \quad (4)$$

qo'shimcha shartlarni qanoatlantiruvchi $\{U(x, t), f(t)\}$ funksiyalar juftligi topilsin, bu yerda $a(x), v(x), \varphi(t)$ -berilgan funksiyalar bo'lib, $a(0) = \varphi(0)$ shartni bajaradi, λ - berilgan haqiqiy son.

Teorema. Agar $\varphi(t) \in C^2\left[0, \frac{1}{2}\right]$, $a(x) \in C^2[0, 1]$, $v(x) \in C^1[0, 1]$, $\varphi(0) = a(0)$, $\varphi'(0) = a'(0) - \lambda a(0) + v(0)$ shartlar bajarilsa, u holda T masalaning yechimi mavjud va yagona bo'lib, u

$$U(x, t) = \frac{a(x-t) + a(x+t)}{2} - \frac{\lambda}{2} \int_0^{x-t} e^{-\lambda(x-t-\xi)} a(\xi) d\xi - \frac{\lambda}{2} \int_0^{x+t} e^{-\lambda(x+t-\xi)} a(\xi) d\xi + \\ + \frac{1}{2} \int_{x-t}^{x+t} v(z) dz + \int_0^t (t-\eta) f(\eta) d\eta \quad (6)$$

va

$$f(t) = \varphi''(t) - 2v'(2t) - 2a''(2t) + \\ + 2\lambda a'(2t) - 2\lambda^2 a(2t) + 2\lambda^3 \int_0^x e^{-\lambda(x-\xi)} a(\xi) d\xi \quad (7)$$

tengliklar bilan aniqlanadi.

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NORAVSHAN MANTIQ ASOSIDA VETERINARIYA KASALLIKLARINI DIAGNOSTIKA QILISH

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Annotatsiya: Ushbu maqolada, veterinariya kasalliklari noaniqlikka asoslangan qiymatlar orqali tizimli tahlil qilinib, noravshan mantiqiy yondashuvlar asosida intellektual diagnostika jarayoni taklif etiladi. Ushbu yondashuv klinik belgilarni aniq raqamlashtirish va noaniq

ma'lumotlarni matematik jihatdan qayta ishlash imkonini beradi. Natijada murakkab va to'liq bo'lmagan ma'lumotlar sharoitida ham ishonchli qaror qabul qilishga erishiladi. Noravshan to'plamlar nazariyasi, veterinariya kasalliklarini erta bosqichda aniqlash, tashxis aniqligini oshirish hamda diagnostika jarayonining samaradorligini kuchaytirishda muhim ilmiy va amaliy ahamiyat kasb etadi.

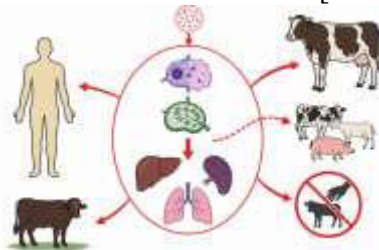
Kalit so'zlar: Veterinariya diagnostikasi, noravshan to'plamlar nazariyasi, ekspert tizimlar, noaniqlik, klinik ma'lumotlar tahlili, erta tashxislash, qaror qabul qilish tizimlari.

KIRISH

Bugungi kunda sayyoramizda inson va hayvonlar orasida turli kasalliklarning ko'payib borishi dolzarb muammolardan biri bo'lib hisoblanadi. Klinik simptomlar, laborator tahlillar va instrumental tekshiruv natijalarini kompleks baholash orqali kasallik holatini aniqlash tibbiyot hamda veterinariya amaliyotining muhim yo'nalishlaridan biri hisoblanadi. Mazkur jarayonda aniqlik darajasi davolash samaradorligi va keyingi profilaktik choralarini belgilashda asosiy omil bo'lib xizmat qiladi. Shu bilan birga, diagnostik ma'lumotlarning noaniqligi yoki yetarli emasligi, klinik belgilar turlicha namoyon bo'lishi hamda mutaxassislarining individual tajribasi va subyektiv qarorlari tashxis ishonchliligiga sezilarli ta'sir ko'rsatishi mumkin. Yer yuzida millionlab kasallik turlari mavjud bo'lib, ularning aksariyati hayot uchun jiddiy xavf tug'diradi va katta iqtisodiy yo'qotishlarga olib keladi. Sayyoramizdagi barcha yuqumli kasalliklarning 60% ini, yangi paydo bo'layotgan infeksiyalarning esa 75% ini hayvonlardan yuquvchi zoonozlar tashkil etadi[1]. Ayniqsa, chorva hayvonlari kasalliklari nafaqat ularning sog'lig'iga, balki oziq-ovqat xavfsizligi va agrar soha barqarorligiga ham salbiy ta'sir ko'rsatadi[2]. Chorva mollari kasalliklari sababli jahon agrar sektori har yili o'rtacha 358,4 milliard dollar miqdorida to'g'ridan-to'g'ri zarar ko'rmoqda[3]. Shu sababli, kasalliklarni erta aniqlash va aniq tashxislash uchun zamonaviy, noaniqlikni hisobga oluvchi intellektual algoritmlarni ishlab chiqish dolzarb vazifa hisoblanadi.

ASOSIY QISM

Brusellyoz — chorva hayvonlarida reproduktiv tizimni zararlovchi va odamlarga yuqish xususiyatiga ega bo'lgan bakterial zoonoz kasallik hisoblanadi [1-rasm].



1-rasm. Brusellyozning zoonoz tarqalishi

Yana bir muhim jihat — diagnostika va profilaktika choralarining yetarli darajada rivojlanmaganligidir. Zamonaviy tashxislash vositalarining yetishmasligi yoki ulardan samarali foydalanilmasligi kasalliklarni erta aniqlash imkoniyatini cheklaydi. Natijada kasalliklar kech aniqlanadi va ularning asoratlari kuchayadi. Shuningdek, aholining va chorvadorlarning tibbiy hamda veterinariya savodxonligi darajasining yetarli emasligi ham kasalliklarning keng tarqalishiga olib keladi. Profilaktika choralariga e'tiborsizlik, o'z vaqtida mutaxassisga murojaat qilmaslik va noto'g'ri davolash usullaridan foydalanish kasalliklarning og'irlashishiga sabab bo'ladi. Yuqoridagi omillar kasalliklarning tez tarqalishiga olib kelib, ularni erta aniqlash, aniq tashxislash va samarali nazorat qilish uchun zamonaviy, intellektual yondashuvlarni ishlab chiqish zaruratini yanada kuchaytiradi.

Rentgen apparati – suyaklar, bo'g'imlar va ichki organlarning tuzilishi va holatini tasvir orqali ko'rsatadi. U asosan sinishlar, ichki jarohatlar va o'pka kasalliklarini aniqlashda ishlatiladi. Qon tahlil analizatorlari – hayvon qonining tarkibini tez va aniq tahlil qilib, anemiya, infeksiya va yallig'lanish jarayonlarini aniqlaydi. Shuningdek, jigar va buyrak faoliyatini baholashda yordam beradi. Ultrasonografiya (UZI) apparati – ichki organlarni va yumshoq to'qimalarni real vaqt rejimida tekshiradi. Homiladorlikni aniqlash, jigar, buyrak va yurak kasalliklarini tashxislashda muhim ahamiyatga ega. PCR va laboratoriya diagnostika tizimlari – kasallik qo'zg'atuvchilarini

DNK yoki RNK darajasida aniqlaydi(2-rasm). Virusli va bakterial infeksiyalarni erta va aniq tashxislash imkonini beradi.[6] Yuqorida ta'riflangan veterinariya diagnostika qurilmalari, jumladan, rentgen, ultrasonografiya, qon tahlil analizatorlari, PCR va laboratoriya tizimlaridan olingan ma'lumotlar to'plamini tahlil qilishda zamonaviy usullar, jumladan, noravshan to'plamlar nazariyasidan foydalanish hayvonlar kasalliklarini erta aniqlash va ularni prognozlashda muhim o'rin tutadi.



2-rasm. Veterinariya kasalliklarini tashxislovchi qurilmalar NORAVSHAN MANTIQ ASOSIDA VETERINARIYA DIAGNOSTIKASI

Noravshan to'plamlar (fuzzy logic) — bu noaniqlik va to'liq bo'lmagan ma'lumotlar sharoitida qaror qabul qilish va tahlil jarayonlarini amalga oshirishga imkon beruvchi matematik yondashuv bo'lib, u aniq chegaralar bilan ifodalanmaydigan ma'lumotlarni baholashga xizmat qiladi. Veterinariyada esa bu yondashuv rentgen va UZI tasvirlarini talqin qilish, qon tahlillari natijalaridagi noaniqliklarni hisobga olish hamda laboratoriya ma'lumotlari asosida tashxis qo'yish jarayonlarini yanada aniqroq va ishonchli qilishda qo'llaniladi [7].

Noravshan to'plamlar asoschisi hisoblangan Lotfi Zadeh tomonidan 1965-yilda ishlab chiqilgan [8]. Noravshan to'plamlar nazariyasi yo'nalishlari 3-rasmda ko'rsatilgan.



3-rasm. Noravshan mantiq va uning qo'llanilish yo'nalishlari

Veterinariya tibbiyotida kasalliklarni tashxislash ko'pincha aniq bo'lmagan, to'liq bo'lmagan va subyektiv ma'lumotlarga asoslanadi. Masalan, hayvonning ishtahasi, xulqi, tana harorati yoki klinik belgilar har doim ham qat'iy "ha/yo'q" shaklida baholanmaydi. Shu sababli noravshan to'plamlar nazariyasi (Fuzzy Set Theory) bu sohada samarali matematik yondashuv sifatida keng qo'llanilmoqda.

Noravshan to'plamlar veterinariya diagnostikasida hayvonlarda kasallik belgilarining aniq emasligi va noaniq baholanishini matematik ifodalash uchun ishlatiladi. Bu yondashuvda simptomlar "ha/yo'q" tarzida emas, balki 0 dan 1 gacha bo'lgan ehtimollik darajasida baholanadi. Natijada mastit, yuqumli kasalliklar va boshqa patologiyalarni aniqlashda qaror qabul qilish aniqligi oshadi. Bu yo'nalishda noravshan to'plamlar nazariyasi asosida ekspert tizimlar yaratiladi. Veterinar shifokor bilimlari "IF-THEN" qoidalari shaklida tizimlashtiriladi. Tizim simptomlar kombinatsiyasiga qarab kasallik ehtimolini hisoblab, shifokorga qaror qabul qilishda yordam beradi. Neutrosifik yondashuv "fuzzy logic"dan kengroq bo'lib, uch komponentga asoslanadi: **haqiqat (T)**, **noto'g'rilik (F)** va **noaniqlik (I)**. Veterinariya diagnostikasida bu usul simptomlar va laborator natijalar to'liq mos kelmagan holatlarda ishlatiladi[9]. U noaniqlikni alohida hisobga olgani uchun murakkab klinik vaziyatlarda aniqroq qaror qabul qilish imkonini beradi.

Noravshan to'plamlar nazariyasi ko'plab olimlar tomonidan o'rganilgan va tadqiqot ishida bir necha olimlar ishlari o'rganildi (1-jadval).

Noravshan mantiq asosidagi tadqiqotlar tavsifi		
Muallif(lar)	Qoʻllanilgan soha	Diagnostic samaradortik
Zadeh L.A.	Sun'iy intellekt, lingvistika, mantiq, qaror qabul qilish, boshqaruv nazariyasi, ekspert tizimlari va neyron tarmoqlar	Noaniq parametrlar bilan ishlash uchun noravshan mantiq nazariyasini yaratgan
Mamdani E.H.	Noravshan mantiq, Sun'iy intellekt, avtomatik boshqaruv tizimlari	Mamdani fuzzy modeli yaratgan
Sugeno M.	Noravshan boshqaruv tizimlari, Avtomobil boshqaruv, Uchuvchisiz vertolyot boshqaruv, Sanoat jarayonlarini boshqarish	Noravshan o'lchovlar va Sugeno Integral nazariyasini yaratgan
O. Castillo va P. Melin	Noravshan mantiq, Neyro-noravshan tizimlar, Aqlli boshqaruv tizimlari	Murakkab noaniqlikni yanada kuchli boshqarish

Veterinariya kasalliklarini tashxislashda noravshan to'plamlar modellarini qo'llash an'anaviy diagnostika usullariga nisbatan tezkor va aniq qaror qabul qilish imkonini beradi[10]. Bunday yondashuv klinik ma'lumotlardagi noaniqlikni kamaytirish, kasalliklarni erta bosqichda aniqlash hamda veterinariya amaliyotida samarali diagnostik tizimlarni yaratishda muhim ahamiyat kasb etadi.

XULOSA

Ushbu tadqiqotda veterinariya kasalliklarini tashxislash jarayonida ma'lumotlardagi noaniqlik va yetishmovchiliklarni hisobga olish zarurati asoslab berildi. An'anaviy diagnostika usullari ko'pincha subyektiv baholash va to'liq bo'lmagan ma'lumotlarga tayanishi sababli, kasalliklarni erta va aniq aniqlashda ayrim cheklavlarga ega. Shu nuqtayi nazardan, noravshan mantiqiy yondashuvlardan foydalanish diagnostika jarayonining ishonchligini oshirishda muhim ahamiyat kasb etadi. Tadqiqot natijalari shuni ko'rsatadiki, noaniq klinik ma'lumotlarni matematik jihatdan ifodalash va ularni tahlil qilish veterinariya amaliyotida qaror qabul qilish jarayonini sezilarli darajada yaxshilaydi. Ushbu yondashuv kasalliklarni erta bosqichda aniqlash, tashxis aniqligini oshirish hamda veterinariya sohasida zamonaviy intellektual tahlil usullarini rivojlantirishga xizmat qiladi.

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GEOMETRIYA ASOSLARI KURSINING MAZMUNI VA UNI O'QITISHNING NAZARIY-METODOLOGIK ASOSLARI

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Annotatsiya. Mazkur maqolada Geometriya asoslari kursini o'qitishning nazariy asoslari tahlil qilingan. Shuningdek, ushbu kursda o'qitiladigan Minkovskiy fazosi elementlari haqida ma'lumotlar berib o'tilgan.

Kalit so'zlar: *geometriya asoslari, noyevklid geometriyasi, Lobachevskiy geometriyasi, Minkovskiy fazosi va Minkovskiy fazosi elementlari.*

Ma'lumki, "Geometriya asoslari" fani oliy ta'lim muassalarining matematika ta'lim yo'nalishlarida o'qitiladigan fan hisoblanadi. Bu fan noyevklid geometriyasining ilmiy asosi

sifatida paydo bo'lgan. Shuningdek, geometriya fanining o'zi qadimiy fan bo'lib, to'la shakllangan va maktab o'quvchilari uchun birinchi ilmiy fan sifatida o'qitiladigan dars hisoblanadi. Chunki maktab o'quvchilari ilmiy tushunchalar bo'lgan “aksioma”, “teorema”, “isbot” kabi tushunchalar bilan birinchi marta geometriya darslarida tanishadilar. Geometriya faniga xos bo'lgan bu holat oliy o'quv yurtlarida “Geometriya asoslari” faniga ham tegishlidir.

T.Safarov⁴ o'zining ““Geometriya asoslari” fanini o'qitishni zamonaviy bilimlarni qo'llash yo'li bilan takomillashtirish” nomli tadqiqot ishida rivojlangan davlatlarning ba'zi yetakchi universitetlarida “Geometriya asoslari” fani doirasida o'qitalayotgan fan dasturiga kiritilgan, ba'zi mavzularni tahlil qilib chiqqan. Shuningdek, tahlil natijalari asosida quyidagicha fikr bildiradi: “...Bizning fikrimizcha, “Geometriya asoslari” fani dasturi va unda bayon etilishi zarur bo'lgan mavzularni tubdan zamona talabiga mos, yangi fan yo'nalishlarini hisobga olgan holda qayta ishlab chiqish zarur”.

Shu bilan birga tadqiqotchi tomonidan A.Ya.Narmanov va A.S.Sharipovlar tomonidan “Geometriya asoslari” nomli o'quv qo'llanmasida⁵ (2004) berilgan mavzularni takomillashtirish maqsadida 30 soatlik 15 ta mavzlarni qiyosiy tahlilini taklif etadi (1-rasmga qarang).

№	Hozirgi mavzu	qitilayotgan	Taklif qilingan mavzular	soat
1	Kirish. Yevklidning o'limidan asoslash. Euklidiy geometriya.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
2	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
3	Tekislik va tekislikdagi shakllar.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
4	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
5	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
6	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
7	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
8	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
9	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
10	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
11	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
12	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
13	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
14	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
15	Yevklid geometriyasining asoslarini. Euklidiy geometriyasining asoslarini.		Euclidning o'limidan asoslash va unga asoslangan bilimlar.	2
Jami				30

1-rasm. Hozirgi vaqtda “Geometriya asoslari” fanidan o'qitilayotgan va taklif qilingan mavzularning qiyosiy tahlili

Yuqoridagi jadvaldan ko'rinadiki “Geometriya asoslari” fanining katta qismini Minkovskiy fazolari egallab turibdi. Minkovskiy fazosi elementlariga quyidagilar kiradi:

- Psedoyevklid fazosi;
- Psedoyevklid fazosi geometriyasi;
- Minkovskiy tekisligining geometriyasi;
- Galiley tekisligining ta'rifi;
- Galiley tekisligining geometriyasi;
- Galiley tekisligining egri chiziqlarining xususiyatlari⁶.

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ЗАДАЧА ТИПА ДИРИХЛЕ ДЛЯ УРАВНЕНИЯ ТРЕТЬЕГО ПОРЯДКА С РАЗРЫВНЫМ КОЭФФИЦИЕНТОМ

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В области $\Omega = \{(x, y) : -a < x < a, 0 < y < 1\}, a \in R$, рассмотрим следующую задачу.

Задача D. Найти функцию $u(x, y) \in C_{x,y}^{3,2}(\Omega \setminus \{x=0\}) \cap C_{x,y}^{2,1}(\bar{\Omega})$, такую что u_{xxx} имеет односторонние пределы при $x \rightarrow \pm 0$, и выполняются условия

$$\begin{cases} u_{xxx} - \operatorname{sgn} x u_{yy} = 0, x \neq 0, \\ u(a, y) = \varphi_1(y), u(-a, y) = \varphi_2(y), \\ u_x(a, y) = u_x(-a, y), \\ u(+0, y) = u(-0, y), u_x(+0, y) = u_x(-0, y), \\ u_{xx}(+0, y) = u_{xx}(-0, y), \\ u(x, 0) = 0, u(x, 1) = 0, \end{cases} \quad (1)$$

где $\varphi_1(y), \varphi_2(y)$ – заданные непрерывные функции.

Решение задачи D будем искать в виде

$$u(x, y) = \sum_{k=1}^{\infty} X_k(x) \sin \pi k y. \quad (2)$$

Подставив в уравнение (1), получим систему

$$\begin{cases} X_k'''(x) + (\pi k)^2 X_k(x) = 0, 0 < x < a; \\ X_k'''(x) - (\pi k)^2 X_k(x) = 0, -a < x < 0; \\ X_k(a) = \varphi_{1k}, X_k(-a) = \varphi_{2k}, X_k'(a) = X_k'(-a), \\ X_k(+0) = X_k(-0), X_k'(+0) = X_k'(-0), X_k''(+0) = X_k''(-0), \end{cases} \quad (3)$$

где $\varphi_{ik} = 2 \int_0^1 \varphi_i(y) \sin \pi k y dy, i = 1, 2; k = 1, 2, \dots$. Пусть $\lambda = \sqrt[3]{(\pi k)^2 a}$. Удовлетворив условиям задачи (3), имеем систему алгебраических уравнений,

$$\begin{cases} c_1 + c_2 - d_1 - d_2 = 0, c_1 - \frac{1}{2}c_2 - \frac{\sqrt{3}}{2}c_3 + d_1 - \frac{1}{2}d_2 + \frac{\sqrt{3}}{2}d_3 = 0, \\ c_1 - \frac{1}{2}c_2 + \frac{\sqrt{3}}{2}c_3 - d_1 + \frac{1}{2}d_2 + \frac{\sqrt{3}}{2}d_3 = 0, c_1 e^{-\lambda} + e^{\frac{1}{2}\lambda} \left(c_2 \cos\left(\frac{\sqrt{3}}{2}\lambda\right) + c_3 \sin\left(\frac{\sqrt{3}}{2}\lambda\right) \right) = \varphi_{1k}, \\ d_1 e^{-\lambda} + e^{\frac{1}{2}\lambda} \left(d_2 \cos\left(\frac{\sqrt{3}}{2}\lambda\right) - d_3 \sin\left(\frac{\sqrt{3}}{2}\lambda\right) \right) = \varphi_{2k}, \\ -c_1 e^{-\lambda} + e^{\frac{1}{2}\lambda} \left(c_2 \cos\left(\frac{\sqrt{3}}{2}\lambda + \frac{\pi}{3}\right) + c_3 \sin\left(\frac{\sqrt{3}}{2}\lambda + \frac{\pi}{3}\right) \right) = d_1 e^{-\lambda} + e^{\frac{1}{2}\lambda} \left(d_2 \cos\left(\frac{\sqrt{3}}{2}\lambda - \frac{2\pi}{3}\right) - d_3 \sin\left(\frac{\sqrt{3}}{2}\lambda - \frac{2\pi}{3}\right) \right). \end{cases}$$

определитель которого имеет вид

$$\Delta = 6e^{\frac{3}{2}\lambda} \left(\sin\left(\frac{\sqrt{3}}{2}\lambda - \frac{\pi}{6}\right) + \frac{1}{2}e^{-\frac{3}{2}\lambda} \right) \left(2e^{-\frac{3}{2}\lambda} \sin\left(\frac{\sqrt{3}}{2}\lambda - \frac{\pi}{6}\right) + 1 \right) \neq 0. \quad (4)$$

Теорема 1. Решение задачи D единственно тогда и только тогда, когда $\Delta \neq 0, \forall k \in N$.

Теорема 2. При выполнении условий теоремы 1 справедливы следующие оценки, для достаточных больших значений k

$$\left| \frac{d^j X_k(x)}{dx^j} \right| \leq \lambda^j M \frac{|\varphi_{1k}| + |\varphi_{2k}|}{\left| \sin \left(\frac{\sqrt{3}}{2} \lambda - \frac{\pi}{6} \right) + \frac{1}{2} e^{\frac{3}{2} \lambda} \right|}, j = 0, 1, 2, 3; -a \leq x \leq a.$$

Лемма 1. Пусть выполнено неравенство (4). Рассмотрим множество $P_1 = \{p, q \in N, (p, q) = 1 \mid \forall k, n \in N, 6pk^2 \neq q(6n+1)\}$. Пусть $C = \frac{p}{q} \in \mathbb{Q}, p, q \in P_1$. Тогда верно

$$\text{соотношение } \left| \sin \pi \left(Ck^{2/3} - \frac{1}{6} \right) \right| \geq \frac{M}{k^{2/3}}, 0 < M = \text{const}, \forall k \in N.$$

Лемма 2. Пусть выполнены следующие условия: а) верно неравенство (4); в) $C \in R \setminus \mathbb{Q}, C^3 = \frac{p}{q}$, где $p, q \in P_2 = \{p, q \in N, (p, q) = 1 \mid \forall k, n \in N, 216pk^2 \neq q(6n+1)^3\}$.

Тогда справедливо соотношение

$$\left| \sin \pi \left(Ck^{2/3} - \frac{1}{6} \right) \right| \geq \frac{M}{k^{2/3}}, 0 < M = \text{const}, \forall k \in N.$$

Лемма 3. Пусть выполнены следующие условия: а) верно неравенство (4); в) C - алгебраическое число порядка $d \geq 2; C^3 \notin \mathbb{Q}$. Тогда при больших значениях k справедливо соотношение

$$\left| \sin \pi \left(Ck^{2/3} - \frac{1}{6} \right) \right| \geq \frac{M(\varepsilon)}{k^{\frac{10}{3} + \varepsilon}}, 0 < M(\varepsilon).$$

Теорема 3. Пусть выполнены следующие условия: 1). Справедливо соотношение (4);

2). Справедлива лемма 1 или лемма 2; 3). $\varphi_i(y) \in C^4[0, 1], \varphi_i^{(4)}(y) \in C^\alpha[0, 1], \frac{1}{3} < \alpha$,

$\varphi_i(0) = \varphi_i(1) = \varphi_i^{(2)}(0) = \varphi_i^{(2)}(1) = \varphi_i^{(4)}(0) = \varphi_i^{(4)}(1) = 0, i = 1, 2$. Тогда ряд (2) является регулярным решением задачи D .

Теорема 4. Пусть выполнены следующие условия: 1). Справедливо соотношение (4);

2). Справедлива лемма 3; 3). $\varphi_i(y) \in C^6[0, 1], \varphi_i^{(6)}(y) \in C^\alpha[0, 1], \frac{1}{3} < \alpha$,

$\varphi_i^{(2j)}(0) = \varphi_i^{(2j)}(1), i = 1, 2; j = 1, 2, 3$. Тогда ряд (2) является регулярным решением задачи D .

КРАЕВАЯ ЗАДАЧА С РАЗРЫВНЫМИ УСЛОВИЯМИ СКЛЕИВАНИЯ ДЛЯ НАГРУЖЕННОГО УРАВНЕНИЯ ЭЛЛИПТИКО-ГИПЕРБОЛИЧЕСКОГО ТИПА ДРОБНОГО ПОРЯДКА В ПРЯМОУГОЛЬНОЙ ОБЛАСТИ

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Рассмотрим уравнение смешанного типа

$$Lu = u_{xx} + \text{sign} u_{yy} - \rho^2 u(x, y) + \mu(y) D_{0x}^\alpha u(x, 0) = 0 \quad (1)$$

в прямоугольной области $\Omega = \{(x, y): 0 < x < 1, -p < y < q\}$, где $\rho, \mu, p > 0, q > 0$ - заданные действительные числа, $\mu(y) = \mu_1(y)$ при $y \geq 0$, $\mu(y) = \mu_2(y)$ при $y \leq 0$, а

$D_{0x}^\gamma[\cdot]$ - оператор дробного порядка γ в смысле Римана-Лиувилля.

Введем обозначения: $J = \{(x, y) : 0 < x < 1, y = 0\}$,
 $\Omega_1 = \Omega \cap \{(x, y) : x > 0, y > 0\}$, $\Omega_2 = \Omega \cap \{(x, y) : x > 0, y < 0\}$, $\Omega = \Omega_1 \cup \Omega_2 \cup J$.

Задача D_p . Найти в области Ω функцию $u(x, y)$, удовлетворяющую следующим условиям:

$$u(x, y) \in C^1(\overline{\Omega_1} \cup \overline{\Omega_2}) \cap C^2(\Omega_1 \cup \Omega_2), D_{0x}^\alpha u(x, 0) \in C(\Omega_1 \cup \Omega_2); \quad (2)$$

$$Lu(x, y) = 0, \quad (x, y) \in \Omega_1 \cup \Omega_2; \quad (3)$$

$$u(0, y) = 0, \quad u(1, y) = 0, \quad -p \leq y \leq q; \quad (4)$$

$$u(x, q) = \varphi(x), \quad u(x, -p) = \psi(x), \quad 0 \leq x \leq 1; \quad (5)$$

$$u(x, +0) = au(x, -0) + b(x), \quad (x, 0) \in \bar{J}; \quad (6)$$

$$\lim_{y \rightarrow +0} u_y(x, y) = c \lim_{y \rightarrow -0} u_y(x, y) + d(x), \quad (x, 0) \in J, \quad (7)$$

где $\varphi(x), \psi(x), b(x), d(x)$ – заданные достаточно гладкие функции, причем $a, c \in (-\infty, 0) \cup (0, +\infty)$.

Отметим, что в работе [1] для нагруженного парабола-гиперболического уравнения в прямоугольной области изучена начально-граничная задача, в которой методом спектральных разложений установлен критерий единственности решения этой задачи и само решение построено в виде суммы ряда по собственным функциям соответствующей одномерной задачи на собственные значения. Задача Дирихле для уравнения (1) при $\mu(y) = 0, b(x) = d(x) = 0, a = c = 1$ изучалась в работах [2]–[3], а при $\alpha = 0$ – в [4].

В данной работе при всех $\rho \geq 0, -1 < \alpha < 0$ установлены необходимые и достаточные условия единственности решения задачи (1)–(5) в прямоугольной области и само решение построено в виде суммы ряда Фурье. Показана устойчивость решения от граничных функций.

Доказаны следующие теоремы.

Теорема 1. Если существует решение $u(x, y)$ задачи Дирихле, то оно единственно только тогда, когда выполнено условие

$$\Delta_{pq}(n) \equiv c \cos \lambda_n p \cosh \lambda_n q + a \lambda_n \sin \lambda_n p \sinh \lambda_n q \neq 0 \text{ при всех } n \in N, \quad \lambda_n^2 = \rho^2 + \pi^2 n^2.$$

Теорема 2. Пусть функции $\varphi(x), \psi(x), b(x)$, и $d(x)$, удовлетворяют условиям $\psi(x) \in C^4[0, 1], b(x) \in C^5[0, 1], d(x) \in C^3[0, 1], d^{(i)}(0) = d^{(i)}(1), \psi^{(i)}(0) = \psi^{(i)}(1) = 0, i = 0, 2, b^{(j)}(0) = b^{(j)}(1) = 0, j = 0, 2, 4$, и выполнены оценка $|\Delta_{pq}(n)| \geq C_0 e^{\pi n q} > 0$ при всех $n > n_0$. Тогда если $\Delta_{pq}(n) \neq 0$ при всех $n = \overline{1, n_0}$, то задача (1)–(8) имеет единственное

решение, которое определяется рядом $u(x, y) = \sqrt{2} \sum_{n=1}^{+\infty} u_n(y) \sin \pi n x$; если $\Delta_{pq}(n) = 0$ при $n = n_1, n_2, \dots, n_\theta \leq n_0$, то задача (1)–(8) разрешима тогда, когда выполнены условия $\varphi_l = \psi_l = 0, l = n_1, n_2, \dots, n_\theta$ и решение в этом случае определяется рядом [5]:

$$u(x, y) = \sqrt{2} \left[\sum_{n=1}^{n_1-1} + \sum_{n=n_1+1}^{n_2-1} + \dots + \sum_{n=n_\theta+1}^{+\infty} \right] u_n(y) \sin \pi n x + \sum_l A_l u_l(y) \sin \pi n x, \quad A_l = \text{const.}$$

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КРАЕВАЯ ЗАДАЧА ДЛЯ НАГРУЖЕННОГО УРАВНЕНИЯ СМЕШАННОГО ТИПА В ПРЯМОУГОЛЬНОЙ ОБЛАСТИ, КОГДА НАГРУЖЕННАЯ ЧАСТЬ УРАВНЕНИЯ СОДЕРЖИТ СЛЕД ВТОРУЮ ПРОИЗВОДНУЮ ОТ ИСКОМОЙ ФУНКЦИИ

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Рассмотрим уравнение смешанного типа

$$Lu \equiv u_{xx} + \operatorname{sign} u_{yy} - \rho^2 u(x, y) + \mu(y) u_{xx}(x, 0) = 0 \quad (1)$$

в прямоугольной области $\Omega = \{(x, y): 0 < x < 1, -p < y < q\}$, где $\rho, p > 0, q > 0$ – заданные действительные числа, $h(y) = h_1(y)$ при $y \geq 0$, $h(y) = h_2(y)$ при $y \leq 0$, $h_j(y) (j = 1, 2)$ – заданные непрерывно - дифференцируемые функции.

Введем обозначения: $J = \{(x, y): 0 < x < 1, y = 0\}$,

$$\Omega_1 = \Omega \cap \{(x, y): x > 0, y > 0\}, \quad \Omega_2 = \Omega \cap \{(x, y): x > 0, y < 0\}, \quad D = D_1 \cup D_2 \cup J.$$

Задача D . Найти в области Ω функцию $u(x, y)$, удовлетворяющую следующим условиям:

$$u(x, y) \in C^1(\overline{\Omega}) \cap C^2(\Omega_1 \cup \Omega_2), \quad u_{xx}(x, 0) \in C(\Omega_1 \cup \Omega_2); \quad (2)$$

$$Lu(x, y) = 0, \quad (x, y) \in \Omega_1 \cup \Omega_2; \quad (3)$$

$$u(0, y) = 0, \quad u(1, y) = 0, \quad -p \leq y \leq q, \quad (4)$$

$$u(x, q) = \varphi(x), \quad u(x, -p) = \psi(x), \quad 0 \leq x \leq 1, \quad (5)$$

где $\varphi(x), \psi(x)$ – заданные достаточно гладкие функции.

Отметим, что в работах [1-2] для уравнения парабола-гиперболического и эллипτικο-гиперболического типов в прямоугольной области, когда нагруженной частью уравнения содержит след искомой функции изучена начально-граничная задача и задача Дирихле. Методом спектральных разложений установлены критерий единственности решения этих задач и само решения построены в виде суммы рядов по собственным функциям соответствующей одномерной задачи на собственные значения.

Задача Дирихле для уравнения (1) при $\mu(y) = 0$ изучалась в работах [3]–[4].

В данной работе при всех $\rho \geq 0$, установлены необходимые и достаточные условия единственности решения задачи (1)–(5) в прямоугольной области и само решение построено в виде суммы ряда Фурье. Показана устойчивость решения от граничных функций.

Доказаны следующие теоремы.

Теорема 1. Если существует решение $u(x, y)$ задачи D , то оно единственно только тогда, когда выполнено условие

$$\Delta_{pq}(n) \equiv \cos \lambda_n p \operatorname{sh} \lambda_n q + \sin \lambda_n p \operatorname{ch} \lambda_n q + \\ + \frac{\mu_n^2}{\lambda_n} [h_{1n}(q) \sin \lambda_n p + h_{2n}(-p) \operatorname{sh} \lambda_n q] \neq 0 \quad \text{при всех } n \in N, \quad \lambda_n^2 = \rho^2 + \mu_n^2, \quad \mu_n = \pi n.$$

Теорема 2. Пусть функции $\varphi(x)$, $\psi(x)$ и $h_j(x)$ удовлетворяют условиям $\varphi(x) \in C^3[0,1]$, $\varphi(0) = \varphi(1) = \varphi''(0) = \varphi''(1) = 0$, $\psi(x) \in C^3[0,1]$, $\psi(0) = \psi(1) = 0$, $\psi''(0) = \psi''(1) = 0$ и $h_1(y) \in C^1[0,q]$, $h_2(y) \in C^1[-p,0]$, $h_j(0) = 0$, ($j=1,2$) и выполнены оценка $|\Delta_{pq}(n)| \geq C_0 e^{\pi n q} > 0$ при всех $n > n_0$. Тогда если $\Delta_{pq}(n) \neq 0$ при всех $n = \overline{1, n_0}$, то задача (1)–(5) имеет единственное решение, которое определяется рядом $u(x, y) = \sqrt{2} \sum_{n=1}^{+\infty} u_n(y) \sin \pi n x$; если $\Delta_{pq}(n) = 0$ при $n = n_1, n_2, \dots, n_\theta \leq n_0$, то задача (1)–(5) разрешима тогда, когда выполнены условия $\varphi_l = \psi_l = 0$, $l = n_1, n_2, \dots, n_\theta$ и решение в этом случае определяется рядом

$$u(x, y) = \sqrt{2} \left[\sum_{n=1}^{n_1-1} + \sum_{n=n_1+1}^{n_2-1} + \dots + \sum_{n=n_\theta+1}^{+\infty} \right] u_n(y) \sin \pi n x + \sum_l A_l u_l(y) \sin \pi l x, \quad (6)$$

здесь

$$u_l(y) = \begin{cases} \frac{m_l}{\sin \lambda_l p} \Delta_{py}(n), & y > 0, \\ \frac{m_l}{\lambda_l \sin \lambda_l p} B_{py}(n), & y < 0, \end{cases}$$

m_l – произвольная постоянная, $A_l = \text{const}$, в сумме $\sum_l$ индекс l принимает значения $n_1, n_2, \dots, n_\theta$ конечные суммы в (6) следует считать нулями, если верхний предел меньше нижнего,

$$B_{py}(n) = \lambda_n \sin \lambda_n (p + y) + \mu_n^2 h_{2n}(y) \sin \lambda_n p + \mu_n^2 h_{2n}(-p) \sin \lambda_n y.$$

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ОБРАТНАЯ ЗАДАЧА ВОССТАНОВЛЕНИЯ ИСТОЧНИКА В СИСТЕМЕ ПОРОУПРУГОСТИ

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Аннотация. В данной работе рассматривается обратная задача определения распределённого источника в системе пороупругости, описываемой тремя упругими

параметрами в бездиссипативном приближении. Доказана теорема о существовании и единственности решения рассматриваемой задачи в классе $C^{3,2}(\mathbb{R} \times [0, x_0])$.

1. Прямая задача

Рассмотрим задачу о распространении волн на полуограниченной прямой $x \geq 0$ для пористой среды в обратимом приближении, описываемый одномерной однородной системой уравнений [1]:

$$\frac{\partial^2 u_1(t, x)}{\partial t^2} - a_{11} \frac{\partial^2 u_1(t, x)}{\partial x^2} - a_{12} \frac{\partial^2 u_2(t, x)}{\partial x^2} = F_1(t, x), \quad t \in \mathbb{R}, \quad 0 < x \leq x_0, \quad (1.1)$$

$$\frac{\partial^2 u_2(t, x)}{\partial t^2} - a_{21} \frac{\partial^2 u_1(t, x)}{\partial x^2} - a_{22} \frac{\partial^2 u_2(t, x)}{\partial x^2} = F_2(t, x), \quad t \in \mathbb{R}, \quad 0 < x \leq x_0, \quad (1.2)$$

где $\mathbf{F} = (F_1, F_2)$ - вектор массовых сил, $\rho_s = \rho_s^f (1 - d_0)$ и $\rho_l = \rho_l^f d_0$ -- парциальные плотности, ρ_s^f и ρ_l^f -- физические плотности упругого пористого тела и жидкости, соответственно, $\rho = \rho_l + \rho_s$, d_0 - пористость, α_3 , λ , μ - упругие параметры пористой среды, коэффициенты системы определяются на основе работы [1,2,3].

Рассмотрим задачу Коши для системы уравнений пороупругости (1.1) и (1.2) со следующими данными Коши [2,3]:

$$u_1|_{x=0} = \varphi_1(t), \quad t \in \mathbb{R}, \quad \frac{\partial u_1}{\partial x} \Big|_{x=0} = \psi_1(t), \quad t \in \mathbb{R}, \quad (1.3)$$

$$u_2|_{x=0} = \varphi_2(t), \quad t \in \mathbb{R}, \quad \frac{\partial u_2}{\partial x} \Big|_{x=0} = \psi_2(t), \quad t \in \mathbb{R}. \quad (1.4)$$

Здесь $\varphi_1(t)$, $\varphi_2(t)$, $\psi_1(t)$, $\psi_2(t)$, $F_1(t, x)$ и $F_2(t, x)$ - заданные функции.

2. Обратная задача

В данной параграфе исследуется вопрос одновременного определения решения $u_1(t, x)$, $u_2(t, x)$ из системы уравнений (1.1), (1.2) и функции $f_1(x)$, $f_2(x)$ ($F_1(t, x) = g(t)f_1(x)$, $F_2(t, x) = g(t)f_2(x)$), если постоянные α_3 , λ , μ , ρ_s^f , ρ_l^f , d_0 , и функция $g(t)$ — фиксированы, заданы условия (1.3)-(1.6) и

$$u_1|_{t=0} = v_1(x), \quad u_2|_{t=0} = v_2(x), \quad 0 \leq x \leq x_0. \quad (2.1)$$

В дальнейшем предполагаем, что все рассматриваемые функции и вектор-функции дважды непрерывно-дифференцируемы по переменной x и трижды непрерывно-дифференцируемы по переменной по t . Кроме того, считаем известную функцию $g(t) \neq 0$ для $t \in \mathbb{R}$. Также предположим, что выполнены условия согласования данных.

С помощью дифференцирования по времени обе части (1.1) и (1.2), исключением искомых функции $f_1(x)$, $f_2(x)$, а также с помощью выделения

$$v_1 \frac{\partial u_1}{\partial t}, \quad v_2 \frac{\partial u_2}{\partial t}$$

получим интегродифференциальную систему со следившим условием

$$\begin{aligned} a_{11} \frac{\partial^2 v_1}{\partial x^2} + a_{12} \frac{\partial^2 v_2}{\partial x^2} &= \frac{\partial^2 v_1}{\partial t^2} - \frac{g'}{g} \frac{\partial v_1}{\partial t} + \\ &+ \frac{g'}{g} \frac{\partial^2}{\partial x^2} \int_0^t (a_{11} v_1(\tau, x) + a_{12} v_2(\tau, x)) d\tau + \frac{g'}{g} a_{11} v_1''(x) + \frac{g'}{g} a_{12} v_2''(x), \end{aligned} \quad (2.3)$$

$$a_{21} \frac{\partial^2 v_1}{\partial x^2} + a_{22} \frac{\partial^2 v_2}{\partial x^2} = \frac{\partial^2 v_2}{\partial t^2} - \frac{g'}{g} \frac{\partial v_2}{\partial t} +$$

$$+ \frac{g'}{g} \frac{\partial^2}{\partial x^2} \int_0^t (a_{21} v_1(\tau, x) + a_{22} v_2(\tau, x)) d\tau + \frac{g'}{g} a_{21} v_1''(x) + \frac{g'}{g} a_{22} v_2''(x), \quad (2.4)$$

$$v_k|_{x=0} = \varphi'_k(t), \quad \left. \frac{\partial v_k}{\partial x} \right|_{x=0} = \psi'_k(t), \quad k=1,2. \quad (2.5)$$

Задача (2.3)–(2.5) имеет единственное решение.

Теорема. Пусть $\varphi_i(t) \in C^3(\mathbb{R})$, $\psi_i(t) \in C^2(\mathbb{R})$, $(i=1,2)$ и $g(t) \in C^2(\mathbb{R})$, кроме того $g(t) \neq 0$. Пусть также $v_i(x) \in C^2([0, x_0])$, $(i=1,2)$ и удовлетворяют условиям согласования $\varphi_i(0) = v_i(0)$, $(i=1,2)$. Тогда обратная задача (1.1)–(1.6), (2.1), (2.2) имеет единственное решения в окрестности начало координат в классе $C^{3,2}(\mathbb{R} \times [0, x_0])$.

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TRAJECTORY ANALYSIS OF A VOLTERRA-TYPE QUADRATIC STOCHASTIC OPERATOR

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Abstract. We study the trajectory behavior of a parametric Volterra-type quadratic stochastic operator defined on a two-dimensional simplex. The complete set of fixed points is explicitly determined, and their local stability properties are rigorously analyzed and classified as attracting, repelling, or saddle, depending on the parameter values. Furthermore, we show that, depending on the sign of the parameter, any trajectory starting from an arbitrary point of the simplex either diverges or converges to a unique fixed point. The obtained theoretical results are further supported and verified by numerical simulations and graphical representations, which confirm the analytical findings and provide additional insight into the global dynamics of the system.

Let us give the main definitions. Denote $E = \{1, 2, \dots, m\}$. A distribution on the set E is a probability measure $\mathbf{x} = (x_1, \dots, x_m)$, i.e., an element of the simplex:

$$S^{m-1} = \left\{ \mathbf{x} \in \mathbb{R}^m : x_i \geq 0, \sum_{i=1}^m x_i = 1 \right\}.$$

A quadratic operator $V : \mathbf{x} \in \mathbb{R}^m \rightarrow \mathbf{x}' = V(\mathbf{x}) \in \mathbb{R}^m$ is defined by:

$$V : x'_k = \sum_{i,j=1}^m P_{ij,k} x_i x_j, \quad k = 1, \dots, m.$$

is called a Volterra quadratic stochastic operator if its coefficients satisfy the following condition:

$$P_{ij,k} = 0, \quad \text{whenever } k \notin \{i, j\}.$$

The association $\mathbf{x}^0 \mapsto \mathbf{x}'$ defines a map $V : S^{m-1} \rightarrow S^{m-1}$, called the evolution operator. The population evolves by starting from an arbitrary frequency distribution $\mathbf{x}^0$, then passing to the state

$\mathbf{x}' = V(\mathbf{x}^0)$ (the next “generation”), then to the state $\mathbf{x}'' = V(V(\mathbf{x}^0))$, and so on. Thus, the evolution of gene frequencies of the population can be considered as a dynamical system:

$$\mathbf{x}^0, \quad \mathbf{x}' = V(\mathbf{x}^0), \quad \mathbf{x}'' = V(V(\mathbf{x}^0)), \quad \mathbf{x}''' = V^3(\mathbf{x}^0), \dots$$

For a given $\mathbf{x}^0 \in S^{m-1}$, the trajectory $\mathbf{x}^{(n)}$, $n = 0, 1, 2, \dots$ of an initial point $\mathbf{x}^0$ under the action of the operator is defined by $\mathbf{x}^{(n+1)} = V(\mathbf{x}^{(n)})$, where $n = 0, 1, 2, \dots$.

A point $\mathbf{x} \in S^{m-1}$ is called a periodic point of V if there exists an $n \in \mathbb{N}$ such that $V^n(\mathbf{x}) = \mathbf{x}$. The smallest positive integer n satisfying the condition above is called the prime period (or the least period) of the point $\mathbf{x}$. A period-one point is called a fixed point of V . Denote by $\text{Fix}(V)$ the set of all fixed points of the operator V , i.e.,

$$\text{Fix}(V) = \{\mathbf{x} \in S^{m-1} : V(\mathbf{x}) = \mathbf{x}\}.$$

Let $DV(\mathbf{x}^*) = \left(\frac{\partial V_i}{\partial x_j}(\mathbf{x}^*) \right)$ be the Jacobian matrix of V at the point $\mathbf{x}^*$.

Definition 1. [4] A fixed point $\mathbf{x}^*$ is called hyperbolic if its Jacobian $DV(\mathbf{x}^*)$ has no eigenvalues on the unit circle in $\mathbb{C}$.

Definition 2. [4] A hyperbolic fixed point $\mathbf{x}^*$ is called:

1. **attracting** if all the eigenvalues of $DV(\mathbf{x}^*)$ are inside the unit disk;
2. **repelling** if all the eigenvalues of $DV(\mathbf{x}^*)$ are outside the unit disk;
3. **a saddle** otherwise.

We consider the following quadratic stochastic operator (QSO) on the two-dimensional simplex $W : S^2 \rightarrow S^2$:

$$W : \begin{cases} x' = x^2 + 2xy + (1-b)xz, \\ y' = y^2 + (1+b)yz, \\ z' = z^2 + (1+b)xz + (1-b)yz, \end{cases} \quad (1)$$

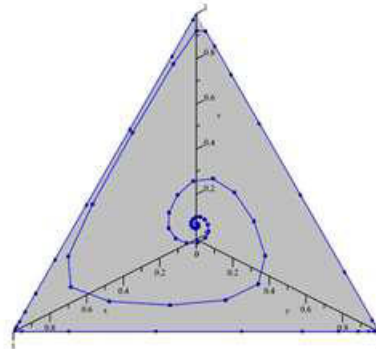
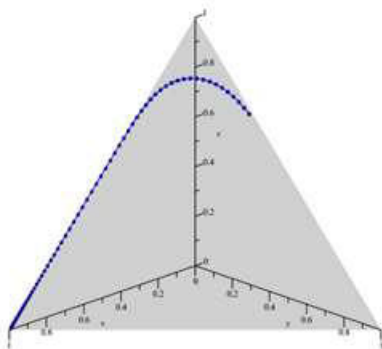
where $b \in [-1; 1]$.

1) $-1 \leq b < 0$.

2) $0 < b \leq 1$

Theorem. The dynamical system generated by the operator (1) satisfies the following statements:

1. $\text{Fix}(W) = \{\mathbf{e}_1, \mathbf{e}_2, \mathbf{e}_3, \mathbf{p}\}$;
2. $\mathbf{e}_1$ is an attracting point if $-1 \leq b < 0$ and a saddle point if $0 < b \leq 1$; $\mathbf{e}_2$ is a repelling point if $-1 \leq b < 0$ and a saddle point if $0 < b \leq 1$; $\mathbf{e}_3$ is a saddle point; and $\mathbf{p}$ is a repelling fixed point;



3. For any initial point $\mathbf{x}^0 \in S^2/\text{Fix}(W)$:
- If $0 < b \leq 1$, then the trajectory is divergent.
 - If $-1 \leq b < 0$, then $\lim_{n \rightarrow \infty} W^n(\mathbf{x}^0) = \mathbf{e}_1$.

where, $\mathbf{e}_1 = (1, 0, 0)$, $\mathbf{e}_2 = (0, 1, 0)$, $\mathbf{e}_3 = (0, 0, 1)$, $\mathbf{p} = \left(\frac{b}{2b+1}, \frac{b}{2b+1}, \frac{1}{2b+1} \right)$.

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ON THE TRAJECTORY BEHAVIOR OF A VOLTERRA-TYPE QUADRATIC STOCHASTIC OPERATOR

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Abstract. We study the trajectory behavior of a parametric Volterra-type quadratic stochastic operator on a two-dimensional simplex. The complete set of fixed points is found, and their local stability (attracting, repelling, and saddle) is characterized based on the parameter. We prove that depending on the sign of the parameter, any trajectory starting outside the fixed and periodic points either diverges or converges to the fixed point.

Let us give the main definitions. Denote $E = \{1, 2, \dots, m\}$. A distribution on the set E is a probability measure $\mathbf{x} = (x_1, \dots, x_m)$, i.e., an element of the simplex:

$$S^{m-1} = \left\{ \mathbf{x} \in \mathbb{R}^m : x_i \geq 0, \sum_{i=1}^m x_i = 1 \right\}.$$

A quadratic operator $V : \mathbf{x} \in \mathbb{R}^m \rightarrow \mathbf{x}' = V(\mathbf{x}) \in \mathbb{R}^m$ is defined by:

$$V : x'_k = \sum_{i,j=1}^m P_{ij,k} x_i x_j, \quad k = 1, \dots, m.$$

is called a **Volterra quadratic stochastic operator** if its coefficients satisfy the following condition:

$$P_{ij,k} = 0, \quad \text{whenever } k \notin \{i, j\}.$$

The association $\mathbf{x}^0 \mapsto \mathbf{x}'$ defines a map $V : S^{m-1} \rightarrow S^{m-1}$, called the evolution operator. The population evolves by starting from an arbitrary frequency distribution $\mathbf{x}^0$, then passing to the state $\mathbf{x}' = V(\mathbf{x}^0)$ (the next “generation”), then to the state $\mathbf{x}'' = V(V(\mathbf{x}^0))$, and so on. Thus, the evolution of gene frequencies of the population can be considered as a dynamical system:

$$\mathbf{x}^0, \quad \mathbf{x}' = V(\mathbf{x}^0), \quad \mathbf{x}'' = V(V(\mathbf{x}^0)), \quad \mathbf{x}''' = V^3(\mathbf{x}^0), \dots$$

For a given $\mathbf{x}^0 \in S^{m-1}$, the trajectory $\mathbf{x}^{(n)}$, $n = 0, 1, 2, \dots$ of an initial point $\mathbf{x}^0$ under the action of the operator is defined by $\mathbf{x}^{(n+1)} = V(\mathbf{x}^{(n)})$, where $n = 0, 1, 2, \dots$.

A point $\mathbf{x} \in S^{m-1}$ is called a periodic point of V if there exists an $n \in \mathbb{N}$ such that $V^n(\mathbf{x}) = \mathbf{x}$. The smallest positive integer n satisfying the condition above is called the prime period (or the least period) of the point $\mathbf{x}$. A period-one point is called a fixed point of V . Denote by $\text{Fix}(V)$ the set of all fixed points of the operator V , i.e.,

$$\text{Fix}(V) = \{\mathbf{x} \in S^{m-1} : V(\mathbf{x}) = \mathbf{x}\}.$$

Let $DV(\mathbf{x}^*) = \left(\frac{\partial V_i}{\partial x_j}(\mathbf{x}^*) \right)$ be the Jacobian matrix of V at the point $\mathbf{x}^*$.

Definition 1. [5] A fixed point $\mathbf{x}^*$ is called hyperbolic if its Jacobian $DV(\mathbf{x}^*)$ has no eigenvalues on the unit circle in $\mathbb{C}$.

Definition 2. [5] A hyperbolic fixed point $\mathbf{x}^*$ is called:

4. **attracting** if all the eigenvalues of $DV(\mathbf{x}^*)$ are inside the unit disk;
5. **repelling** if all the eigenvalues of $DV(\mathbf{x}^*)$ are outside the unit disk;
6. **a saddle** otherwise.

We consider the following quadratic stochastic operator (QSO) on the two-dimensional simplex $W : S^2 \rightarrow S^2$:

$$W : \begin{cases} x' = x^2 + (1+a)xy + 2xz, \\ y' = y^2 + (1-a)xy, \\ z' = z^2 + 2yz, \end{cases} \quad (1)$$

where $a \in [-1; 1]$.

Theorem. The dynamical system generated by the operator (1) satisfies the following statements:

1. $\text{Fix}(W) = \{\mathbf{e}_1, \mathbf{e}_2, \mathbf{e}_3, \mathbf{c}\}$;
2. $\mathbf{e}_1$ is a saddle point if $-1 \leq a < 0$ and an attracting point if $0 < a \leq 1$; $\mathbf{e}_2$ is a saddle point if $-1 \leq a < 0$ and a repelling point if $0 < a \leq 1$; $\mathbf{e}_3$ is a saddle point; and $\mathbf{c}$ is a repelling fixed point;
3. For any initial point $\mathbf{x}^0 \in S^2 / \text{Fix}(W)$:
 - If $-1 \leq a < 0$, then the trajectory is divergent.
 - If $0 < a \leq 1$, then $\lim_{n \rightarrow \infty} W^n(\mathbf{x}^0) = \mathbf{e}_1$.

where, $\mathbf{e}_1 = (1, 0, 0)$, $\mathbf{e}_2 = (0, 1, 0)$, $\mathbf{e}_3 = (0, 0, 1)$, $\mathbf{c} = \left(\frac{1}{2-a}, \frac{1}{2-a}, \frac{a}{a-2} \right)$.

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A CONGRUENCE-SIMPLE ALGEBRA WHICH IS NOT TRANSLATION- PRECOMPLETE

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Abstract. It is shown that the existence of a congruence-simple algebra that is not a translation complete algebra.

Keywords: Universal algebra, equivalence, numbered algebra, negativity, positivity, translation complete algebra.

All undefined notions may be found in the works of H.Rogers [1], Yu.L.Ershov [2], Yu.L.Ershov and S.S.Goncharov [3], N.Kh.Kasymov [4], I.A.Khodzhamuratova [5].

Let η be a fixed equivalence relation on ω . Any algebra possessing a numbering whose kernel coincides with η will be called an η -algebra (or definable over η). In other words, an algebra A is definable over the equivalence η if there exists a computable algebra

$$\langle \omega, F \rangle$$

where F is a computable family of computable functions, such that η is a congruence of the algebra $\langle \omega, F \rangle$ and A is isomorphic to the factor algebra $\langle \omega, F \rangle$

Let η be an equivalence relation on ω . A subset $\alpha \subseteq \omega$ is called η -closed if

$$x \in \alpha \wedge x \equiv y (\text{mod } \eta) \Rightarrow y \in \alpha,$$

that is, if α is the union of certain η -classes. An η -closed set is called η -finite (η -infinite, η -co-infinite) if it is the union of a finite (infinite, respectively co-infinite) collection of η -classes.

A congruence θ of a universal algebra A of signature Σ is any equivalence relation on A preserving all operations, i.e.,

$$\forall f \in \Sigma \forall \bar{x} \equiv \bar{y} (\text{mod } \theta) \Rightarrow f(\bar{x}) \equiv f(\bar{y}) (\text{mod } \theta).$$

If an algebra has no nontrivial congruences other than the trivial congruence idA and the universal congruence A^2 , then it is called congruence-simple.

Definition 1. An algebra is called subdirectly irreducible if the intersection of all its nonzero congruences is itself a nonzero congruence [1].

In other words, such an algebra admits no separating family of nonzero congruences whose factor direct product approximates the algebra.

We shall consider properties of equivalence relations that arise as kernels of numberings of universal algebras satisfying certain finiteness conditions on the lattices of their congruences, in particular, congruence-simple and subdirectly irreducible algebras.

It is known ([4]) that over every negative equivalence relation there exist representable finitely generated as well as congruence-simple universal algebras. On the other hand, representability of a congruence-simple algebra over a positive equivalence relation is equivalent to its decidability. Moreover, if an equivalence relation (not necessarily positive) possesses, for example, a hyperimmune characteristic transversal, then every finite-signature algebra representable over it is locally finite ([5]). If a positive equivalence relation is not computably separable, then the congruence lattice of every universal algebra representable over it has continuum cardinality ([5]). Therefore, from the viewpoint of representability of rich classes of systems over equivalence relations, negative equivalence relations may be regarded as more preferable than positive ones. The following important classes of universal algebras support this observation.

A unary term operation with fixed elements of the algebra as parameters is called a translation.

Definition 2. A universal algebra is called translation-complete if every pair of distinct elements can be mapped to any other pair of distinct elements by an appropriate translation.

Obviously, every translation-complete algebra is congruence-simple. The converse is false.

Definition 3. A universal algebra is called translation-precomplete if there exists a pair of distinct elements into which every pair of distinct elements can be mapped by an appropriate translation.

Note that we assume the existence of a translation $t: \forall x [t(x) = x]$ in the translations semigroup.

It follows directly from the definition that every translation-precomplete algebra is subdirectly irreducible. The converse is false.

Definition 3 is substantially more general than Definition 2.

Clearly, translation precompleteness implies subdirect irreducibility of an algebra (since the intersection of all nonzero congruences is nonzero). However, in general, subdirect irreducibility does not imply translation precompleteness.

Consider the cyclic group

$$\mathbb{Z}_p$$

where p is a prime number and $p \neq 2$.

Since p is prime, the group $\mathbb{Z}_p$ is a congruence-simple.

Hence the group $\mathbb{Z}_p$, $p \neq 2$ is not translation-precomplete.

Thus, it has been established that the group $\mathbb{Z}_p$, $p \neq 2$ is congruence-simple but not translation-complete.

This example demonstrates that the converse of the statement

“Every translation-complete algebra is congruence-simple”

is false in general case for classical systems.

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MOSLANGAN MANBALI VAQTGA BOG‘LIQ KOEFFITSIYENTLI QO‘SHIMCHA HADLI KENGAYTIRILGAN BESHINCHI TARTIBLI KORTEVEG-DE FRIZ TENGLAMASI UCHUN KOSHI MASALASI

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Annotatsiya: Mazkur tezisda, Moslangan manbali vaqtga bog‘liq koeffitsiyentli qo‘shimcha hadli kengaytirilgan 5-tartibli Korteveg-de Friz tenglamasi uchun Koshi masalasi Shturm-Liuvill operatori uchun sochilish nazariyasining teskari masalalari usulida yechilgan.

Bizga quyidagi

$$\begin{cases} u_t + u_{xxxx} - 20u_x u_{xx} - 10uu_{xxx} + 30u^2 u_x + \alpha(t)(u_{xxx} - 6uu_x) + \gamma(t)u_x = 4 \sum_{m=1}^N \frac{\partial}{\partial x} |\varphi_m|^2 \\ -\varphi_m'' + u(x,t)\varphi_m = k_m^2 \varphi_m \end{cases} \quad (1)$$

moslangan manbali vaqtga bog'liq koeffitsiyentli kengaytirilgan beshinchi tartibli Korteveg-de Friz tenglamasi qaraylik. Bu yerda $\alpha(t)$ va $\gamma(t)$ oldindan berilgan uzluksiz differensiallanuvchi funksiyalar. Qaralayotgan holda $\varphi_m = \varphi_m(x,t), m = \overline{1, N}$ funksiyalar

$$L(t) := -\frac{d^2}{dx^2} + u(x,t), t > 0$$

operatorning xos qiymatlarga mos keluvchi xos funksiyalardan iborat bo'lib, quyidagi

$$\int_{-\infty}^{+\infty} |\varphi_m(x,t)|^2 dx = A_m(t), m = \overline{1, N} \quad (2)$$

shartlarni qanoatlantiradi. Bu yerda $A_m(t), m = \overline{1, N}$ berilgan musbat funksiyalar.

Berilgan (1) tenglamani quyidagi

$$u(x,0) = u_0(x), \quad x \in \mathbb{R}, \quad (3)$$

boshlang'ich shart bilan o'rganamiz. Bu yerda $u_0(x)$ – haqiqiy funksiya bo'lib, quyidagi xossalarga ega:

1)

$$\int_{-\infty}^{\infty} (1+|x|)|u_0(x)|dx < \infty \quad (4)$$

2) $L(0) = -\frac{d^2}{dx^2} + u_0(x), x \in \mathbb{R}$ operator N ta $\lambda_1(0), \lambda_2(0), \dots, \lambda_N(0)$ xos qiymatlarga ega

va spektral maxsusliklarga ega emas.

Faraz qilaylik $u(x,t)$ ushbu

$$\int_{-\infty}^{\infty} \left[(1+|x|)|u(x,t)| + \sum_{j=1}^3 \left| \frac{\partial^j u(x,t)}{\partial x^j} \right| \right] dx < \infty, \quad \forall t \geq 0 \quad (5)$$

shartni qanoatlantirsin.

Bu (1)-(5) masalaning asosiy maqsadi sochilish nazariyasining teskari masalalari usuli yordamida $u(x,t), \varphi_m(x,t), m = \overline{1, N}$ funksiyalarni topishdan iborat.

Mazkur ishning asosiy natijasi quyidagi teoremdan iboratdir.

Teorema. Agar $u(x,t), \varphi_m(x,t), m = \overline{1, N}, x \in \mathbb{R}, t > 0$ funksiyalar (1)-(5) masalaning yechimi bo'lsa, u holda $u(x,t)$ potentsiali $L(t)$ operatorining $r^+(k,t), \lambda_m(t), B_m(t), m = \overline{1, N}$ sochilish nazariyasining berilganlari quyidagi differensial tenglamalarni qanoatlantiradi:

$$\frac{\partial r^+(k,t)}{\partial t} = 32ik^5 + 8ik^3\alpha(t) + 2ik\gamma(t) r^+(k,t),$$

$$\frac{\partial \lambda_m(t)}{\partial t} = 0, m = \overline{1, N},$$

$$\frac{dB_n(t)}{dt} = 32ik_n^5 + 8ik_n^3\alpha(t) - 2ik_n\gamma(t) B_n(t), n = \overline{1, N}.$$

Foydalanilgan adabiyotlar.

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ЗАДАЧА С НЕЛОКАЛЬНЫМИ УСЛОВИЯМИ ДЛЯ УРАВНЕНИЯ СМЕШАННОГО ТИПА С ДВУМЯ СИНГУЛЯРНЫМИ КОЭФФИЦИЕНТАМИ В ПАРАЛЛЕЛЕПИПЕДЕ

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В данной работе рассмотрим уравнение

$$u_{xx} + \operatorname{sgn} y u_{yy} + u_{zz} + \frac{2\beta}{|y|} u_y + \frac{2\gamma}{z} u_z = 0 \quad (1)$$

в области $\Omega^\infty \setminus \{y=0\}$, где $\Omega^\infty = \{(x, y, z) : x \in (0, a), y \in (-b, +\infty), z \in (0, c)\}$, $a, b, c \in \mathbb{R}^+$, а $\beta, \gamma \in (0, 1/2)$.

Уравнение (1) в области Ω^∞ принадлежит смешанному типу, а именно в области $\Omega_+^\infty = \Omega^\infty \cap \{y > 0\}$ принадлежит эллиптическому типу, а в области $\Omega_-^\infty = \Omega^\infty \cap \{y < 0\}$ – гиперболическому типу. Плоскости $y=0$ и $z=0$ являются плоскостями сингулярности коэффициентов уравнения. Среди них $y=0$ – плоскость изменения типа уравнения.

В области Ω для уравнения (1) исследуем следующую задачу:

Задача B_1^∞ . Найти функцию $u(x, y, z)$, удовлетворяющую в области $\Omega^\infty \setminus \{y=0\}$ уравнению (1) и условиям

$$\begin{aligned} u(x, y, z) &\in C(\bar{\Omega}) \cap C_{x,y,z}^{2,2,2}(\Omega_+^\infty \cup \Omega_-^\infty), \quad u_x, z^{2\gamma} u_z \in C(\bar{\Omega}), \\ u(0, y, z) &= u(a, y, z), \quad u_x(0, y, z) = 0, \quad y \in [0, b], \quad z \in [0, c], \\ u(x, 0, z) &= \tau(x, z), \quad \lim_{y \rightarrow +\infty} u(x, y, z) = 0, \quad x \in [0, a], \quad z \in [0, c], \\ u(x, y, 0) &= 0, \quad u(x, y, c) = 0, \quad x \in [0, a], \quad y \in [0, b], \end{aligned}$$

а также условию склеивания

$$\lim_{y \rightarrow -0} (-y)^{2\beta} u_y(x, y, z) = \lim_{y \rightarrow +0} y^{2\beta} u_y(x, y, z), \quad x \in (0, a), \quad z \in (0, c),$$

где $\tau(x, z)$ – заданная функция.

Нелокальные задачи возникают при исследовании физических явлений в случае, когда граница области протекания недоступна для непосредственных измерений. Например, математическое моделирование процессов распространения тепла [1], [2], процессы влагопереноса в капиллярно пористых средах [3] приводятся к таким задачам. Задачи с нелокальными интегральными условиями в настоящее время активно изучаются, а методы доказательства их разрешимости разрабатываются (см. например [4], [5]).

Спецификой поставленной нелокальной задачи является несамосопряженность дифференциального оператора и, как следствие, неполнота системы собственных функций,

которую приходится пополнять присоединенными функциями. Фундаментальные результаты относительно базисности системы собственных и присоединенных функций получены в работах [6], [7].

Доказана следующая теорема.

Теорема. Пусть функции $\tau(x, z)$ удовлетворяют следующим условиям:

- I. $\tau(x, z) \in C_{x,z}^{4,5}(\bar{\Pi})$, где $\Pi = \{(x, z) : x \in (0, a), z \in (0, c)\}$;
- II. $\left(\partial^j / \partial x^j\right) \tau(x, z) \Big|_{x=0} = \left(\partial^j / \partial x^j\right) \tau(x, z) \Big|_{x=a}$, $j = \overline{0, 3}$;
- III. $\left(\partial^j / \partial z^j\right) \tau(x, z) \Big|_{z=0} = 0$, $\left(\partial^j / \partial z^j\right) \tau(x, z) \Big|_{z=c} = 0$, $j = \overline{0, 4}$

и выполнена оценка $|\Delta_{nm}(b_0, b)| \geq C_0 e^{\sqrt{\lambda_{nm}}b}$ при $n > n_0$, $m > m_0$. Тогда

1) если $\Delta_{nm}(b_0, b) \neq 0$ при всех $n = 1, 2, \dots, n_0$, $m = 1, 2, \dots, m_0$, то существует единственное решение задачи B_1 ;

2) если $\Delta_{nm}(b_0, b) = 0$ при некоторых $n = s_1, s_2, \dots, s_j \leq n_0$, $m = t_1, t_2, \dots, t_i \leq m_0$ и выполняются условия

$$\int_0^c \int_0^a \tau(x, z) X_l(x) z^{1/2+\gamma} J_{1/2-\gamma}(\sigma_k z/c) dx dz = 0$$

$l = s_1, s_2, \dots, s_n$, $k = t_1, t_2, \dots, t_m$, то решение задачи B_1^∞ существует, где

$$\Delta_{nm}(b_0, b) = I_{1/2-\beta}(\sqrt{\lambda_{nm}}b) \bar{Y}_{1/2-\beta}(\sqrt{\lambda_{nm}}b_0) + K_{1/2-\beta}(\sqrt{\lambda_{nm}}b) J_{1/2-\beta}(\sqrt{\lambda_{nm}}b_0),$$

$$\bar{Y}_{1/2-\beta}(x) = \frac{\pi}{2 \cos \beta \pi} \{J_{1/2-\beta}(x) + J_{\beta-1/2}(x)\},$$

$$\tau_{jnm} = d_m \int_0^c \int_0^a \tau_j(x, z) X_n(x) z^{2\gamma} Z_m(z) dx dz, \quad j = \overline{1, 2}, \quad d_m = 2 / [c J_{3/2-\gamma}(\sigma_m)]^2,$$

$J_\nu(x)$, $I_\nu(x)$ и $K_\nu(x)$ – функция Бесселя первого рода, функция Бесселя мнимого аргумента и функция Макдональда порядка ν [8] соответственно,

$\lambda_{nm} = (2\pi n/a)^2 + (\sigma_{\gamma m}/c)^2$, $n+1, m \in N$, а $\sigma_m - m$ -ый положительный корень уравнения

$$J_{1/2-\gamma}(z) = 0, \quad X_n(x) = \left\{ \frac{1}{\sqrt{a}}, \sqrt{\frac{2}{a}} \sin \frac{2\pi n x}{a}, \sqrt{\frac{2}{a}} \cos \frac{2\pi n x}{a} \right\}, n \in N.$$

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A -UNIFORMALLASHTIRISH ORQALI INDUKSIYALANGAN A -PUANKARE METRIKASI: GEODEZIK TUZILMA, CHEGARAVIY XOSSALARI VA TO'LIQLIK

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Annotatsiya

Ushbu tezisdagi birlik diskning klassik Puankare metrikasini A-uniformallashtiruvchi akslantirish orqali giperbolik sohaga tortib olish natijasida hosil bo'ladigan geometriya o'rganiladi. Induksiyalangan metrika A-Puankare metrikasi sifatida qaraladi va u A-analitik tuzilma bilan jihozlangan sohalar uchun klassik giperbolik geometriyaning tabiiy umumlashmasi sifatida talqin qilinadi.

Ishning asosiy maqsadi Puankare disk modelining fundamental xossalari ushbu umumlashgan uniformallashtirish sharoitida qanchalik saqlanishini aniqlashdan iborat. Har qanday bo'lakli silliq egri chiziqning induksiyaalangan metrikadagi uzunligi uning birlik diskdagi obrazining Puankare uzunligiga teng ekanini ko'rsatiladi. Natijada A-geodeziklar klassik giperbolik geodeziklarning teskari obrazlari ekanligi isbotlanadi. Shuningdek, uniformallashtiruvchi akslantirish mos metrik fazolar orasida izometriya bo'lishi aniqlanadi. Bundan tashqari, sohaning chegarasi induksiyaalangan metrikada cheksiz uzoqlikda joylashgani va hosil bo'lgan metrik fazo to'liq ekanini isbotlanadi. Golomorf holatda esa induksiyaalangan metrika o'zgarish -1 Gauss egriligiga ega bo'ladi. Demak, klassik Puankare geometriyasi ushbu konstruksiyaning xususiy holati sifatida namoyon bo'ladi.

Kalit so'zlar: A-Puankare metrikasi, Puankare metrikasi, A-uniformallashtirish, giperbolik geometriya, geodezik, tortma metrika, to'liqlik.

1. Kirish

Puankare metrikasi kompleks analiz, geometrik funksiyalar nazariyasi va Riman sirtlari nazariyasining markaziy obyektlaridan biridir. Birlik disk $\mathbb{D}$ da u o'zgarish manfiy Gauss egriligiga ega bo'lgan ikki o'lchovli giperbolik geometriyaning to'liq modelini hosil qiladi. Uning asosiy geometrik xossalari yaxshi ma'lum: geodeziklar diametrlar hamda chegaraga ortogonal bo'lgan aylana yo'li orqali ifodalanadi, disk chegarasi esa har bir ichki nuqtadan cheksiz uzoqlikda joylashgan bo'ladi.

Ixtiyoriy giperbolik sohalar uchun klassik giperbolik geometriya odatda konform uniformallashtirish yordamida quriladi. Agar golomorf uniformallashtiruvchi akslantirish berilgan sohani birlik diskka akslantirsa, u holda Puankare metrikasini tortib olish orqali diskning giperbolik geometriyasi dastlabki sohaga ko'chiriladi. Biroq umumlashgan analitik funksiyalar, Beltrami tipidagi tenglamalar va Vekua tipidagi tuzilmalar bilan bog'liq masalalarda faqat konform akslantirishlar emas, balki A-analitik tuzilma bilan mos keluvchi akslantirishlarni qarash tabiiy hisoblanadi.

Shu sababli quyidagi savol yuzaga keladi: Puankare metrikasining asosiy geometrik xossalari metrika A-uniformallashtirish orqali induksiyaalangan ham saqlanadimi? Ushbu tezis aynan shu savolga bag'ishlanadi va giperbolik sohada A-Puankare metrikasini qurish hamda uning asosiy xossalarni o'rganishga qaratiladi.

2. Tadqiqot obyekti va maqsadi

Ω giperbolik soha bo'lsin va

$$\Phi: \Omega \rightarrow \mathbb{D}$$

berilgan A -analitik tuzilma bilan mos keluvchi biyektiv A -diffeomorfizm bo'lsin. Bu yerda $\mathbb{D}$ birlik diskni bildiradi. $\mathbb{D}$ dagi klassik Puankare metrikasi quyidagicha beriladi:

$$ds_{\mathbb{D}}^2 = \frac{4|dw|^2}{(1-|w|^2)^2}.$$

Ω sohasida A -Puankare metrikasi birlik diskdagi klassik Puankare metrikasining Φ akslantirish bo'yicha teskari obraz metrikasi sifatida aniqlanadi:

$$ds_A^2 = \Phi^*(ds_{\mathbb{D}}^2).$$

Tadqiqot obyekti

$$(\Omega, ds_A^2)$$

fazoda hosil bo'ladigan metrik geometriyadan iborat.

Tadqiqotning maqsadi induksiyalangan metrika birlik diskning asosiy giperbolik xossalarini, ya'ni uzunlikning saqlanishi, geodeziklar mosligi, izometriya, chegaragacha bo'lgan masofaning cheksizligi, to'liqlik hamda konform holatda o'zgaras egrilik xossalarini saqlashini isbotlashdan iborat.

3. Tadqiqot metodologiyasi

Tadqiqot Riman metrikalarini tortib olish konstruksiyasi va Puankare diskining klassik geometrik xossalariga asoslanadi. Asosiy usul Ω sohadagi egri chiziqlarni ularning Φ akslantirish ostidagi birlik diskdagi obrazlari bilan taqqoslashdan iborat. Induksiyalangan metrika Puankare metrikasini tortib olish orqali aniqlangani sababli, Ω dagi egri chiziq uzunligi uning $\mathbb{D}$ dagi obrazining uzunligi orqali bevosita ifodalanadi.

Ushbu kuzatish geodeziklarning variatsion tavsifini, masofa baholarini va to'liqlik xossasini diskdan Ω sohaga ko'chirish imkonini beradi.

4. Asosiy natijalar

Birinchi natija uzunlikning saqlanishiga taalluqlidir. Agar γ — Ω dagi bo'lakli silliq egri chiziq bo'lsa, u holda uning A -Puankare metrikasiga nisbatan uzunligi quyidagi tenglikni qanoatlantiradi:

$$L_A(\gamma) = L_{\mathbb{D}}(\Phi \circ \gamma).$$

Demak, induksiyalangan metrika egri chiziqning giperbolik uzunligini birlik diskdagi obrazga o'tganda buzmaydi. Ushbu ayniyat butun konstruksiyaning asosiy tayanch natijasi hisoblanadi.

Ikkinchi natija geodeziklarni tavsiflaydi. Ω dagi γ egri chiziq A -geodezik bo'lishi uchun $\Phi \circ \gamma$ egri chiziq birlik diskdagi klassik Puankare metrikasining geodezigi bo'lishi zarur va yetarlidir. Shuning uchun A -geodeziklar aynan Φ akslantirish ostida birlik aylanasiga ortogonal bo'lgan diametrlar va aylana yo'ylarining teskari obrazlaridir. Bu esa induksiyalangan metrika geodezik tuzilmasi to'liq ravishda $\mathbb{D}$ diskning giperbolik geometriyasi bilan aniqlanishini ko'rsatadi.

Uchinchi natija Φ akslantirishning metrik fazolar orasidagi izometriya ekanligini ifodalaydi. Agar d_A — A -Puankare metrikasi tomonidan hosil qilingan masofa, $d_{\mathbb{D}}$ esa diskdagi Puankare masofasi bo'lsa, u holda

$$d_A(z_1, z_2) = d_{\mathbb{D}}(\Phi(z_1), \Phi(z_2)), \quad z_1, z_2 \in \Omega.$$

Natijada (Ω, d_A) metrik fazo A -uniformallashtiruvchi akslantirish orqali Puankare diskiga geometrik jihatdan ekvivalent bo'ladi.

To'rtinchi natija chegaraviy xatti-harakatga tegishlidir. Agar Ω dagi nuqtalar ketma-ketligi $\partial\Omega$ chegaraga yaqinlashsa, u holda ularning Φ ostidagi obrazlari $\partial\mathbb{D}$ birlik aylana chegarasiga yaqinlashadi. Puankare diskida chegara giperbolik metrikaga nisbatan cheksiz uzoqlikda joylashgani sababli, har bir fiksirlangan ichki nuqta $z_0 \in \Omega$ uchun

$$d_A(z_0, z) \rightarrow \infty \text{ agar } z \rightarrow \partial\Omega$$

munosabat bajariladi. Demak, Ω sohaning chegarasi A -Puankare metrikasida cheksiz uzoqlikda joylashadi.

Beshinchi natija metrik to'liqlikdan iborat. (Ω, d_A) dagi har qanday Koshi ketma-ketlik Φ akslantirish orqali to'liq Puankare diskidagi Koshi ketma-ketlikka o'tadi. Shuning uchun u diskda yaqinlashadi, Φ^{-1} ni qo'llash esa uning Ω ichida yaqinlashishini beradi. Demak, (Ω, d_A) metrik fazo to'liqdir.

Nihoyat, Φ golomorf va lokal konform bo'lgan maxsus holatda induksiyalangan metrika o'zgarmas Gauss egriligiga ega bo'ladi:

$$K = -1.$$

Shu sababli klassik Puankare metrikasi A -Puankare konstruksiyasining xususiy holati sifatida olinadi.

5. Ilmiy yangilik

Tadqiqotning ilmiy yangiligi quyidagilardan iborat:

1. A -Puankare metrikasi klassik Puankare metrikasini A -uniformallashtiruvchi akslantirish orqali tortib olish natijasida kiritiladi.

2. Barcha bo'lakli silliq egri chiziqlar uchun uzunlikning saqlanishini ifodalovchi aniq ayniyat isbotlanadi.

3. A -geodeziklar birlik diskdagi klassik giperbolik geodeziklarning teskari obrazlari sifatida tavsiflanadi.

4. A -uniformallashtiruvchi akslantirish induksiyalangan metrik fazo bilan Puankare diski orasidagi izometriya ekanligi ko'rsatiladi.

5. Chegaraning cheksiz uzoqlikda joylashishi va induksiyalangan metrik fazoning to'liqligi isbotlanadi.

6. Konform holat o'zgarmas -1 egrilikka ega bo'lgan klassik Puankare geometriyasi bilan aynan mos kelishi aniqlanadi.

6. Xulosa

Ushbu tezisda A -uniformallashtirish bilan jihozlangan giperbolik sohada A -Puankare metrikasi to'liq giperbolik geometriyani hosil qilishi ko'rsatildi. Mazkur konstruksiya Puankare diskining asosiy metrik va geodezik xossalarini dastlabki sohaga ko'chiradi. Egri chiziqlar uzunligi uniformallashtiruvchi akslantirish ostida saqlanadi, geodeziklar esa disk geodeziklarining teskari obrazlari sifatida hosil bo'ladi. Induksiyalangan masofa esa soha chegarasini cheksiz uzoqlikka olib chiqadi.

Metrik fazoning to'liqligi bevosita Puankare diskining to'liqligidan kelib chiqadi. Golomorf holatda esa metrika o'zgarmas -1 Gauss egriligiga ega bo'ladi. Bu esa klassik Puankare geometriyasi umumiy nazariyaning xususiy holati ekanligini tasdiqlaydi.

Olingan natijalar A -analitik tuzilmalar, A -avtomorfizmlar, umumlashgan uniformallashtirish va anizotrop giperbolik geometriyani keyingi tadqiq qilish uchun qat'iy matematik asos yaratadi.

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ПРОСТРАНСТВЕННО-НЕЛОКАЛЬНЫЕ КРАЕВЫЕ ЗАДАЧИ ДЛЯ ПАРАБОЛИЧЕСКИХ УРАВНЕНИЙ ЧЕТВЁРТОГО ПОРЯДКА.

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В последние годы исследование нелокальных краевых задач для параболических уравнений в частных производных приобретает всё большую актуальность. Это связано с тем, что подобные задачи широко применяются при описании процессов теплопроводности, диффузии, колебаний и других явлений математической физики. Нелокальные краевые задачи с обобщённым условием Самарского–Ионкина подробно рассматриваются в монографии А.И. Кожанова [1], где приведены основные результаты и нерешённые проблемы данной области. Наиболее близкой к тематике настоящего исследования является работа А.И. Кожанова [2], посвящённая изучению нелокальных задач для параболических уравнений второго порядка с краевым условием Самарского.

В данной работе исследуется разрешимость нелокальных задач с обобщённым условием А.А. Самарского для параболических уравнений четвёртого порядка вида

$$u_t + D_x^4 u + c(x, t)u = f(x, t).$$

Основное внимание уделяется вопросам существования, единственности и регулярности

решений. Доказываются теоремы о существовании и единственности регулярных решений,

обладающих всеми необходимыми обобщёнными производными в смысле С.Л. Соболева.

При исследовании применяются современные методы функционального анализа, теория

дифференциальных уравнений и энергетические оценки.

Полученные результаты расширяют существующие подходы к изучению нелокальных задач для уравнений высокого порядка и позволяют более глубоко исследовать свойства решений в сложных математических моделях. Практическая значимость работы заключается в возможности использования полученных выводов при моделировании процессов теплопроводности, диффузии, колебательных процессов и других прикладных задач математической физики.

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ENHANCING HYDRO-TURBINE GOVERNING SYSTEMS VIA FRACTIONAL-ORDER PID CONTROLLERS

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Abstract

The optimization of hydro-turbine governing systems requires managing highly non-linear fluid dynamics and non-minimum phase behaviors. Traditional integer-order PID controllers lack

the degrees of freedom to optimally stabilize these systems under transient conditions. This paper introduces a Fractional-Order Proportional-Integral-Derivative (FOPID) controller model and demonstrates how computational polynomial approximations (Oustaloup's method) enable the digital simulation and implementation of fractional calculus in renewable energy control systems.

1. Introduction

A hydroelectric plant's stability depends heavily on its governing system, which adjusts the guide vane opening to regulate turbine speed against varying electrical load demands. The system exhibits a non-minimum phase characteristic due to the "water hammer" effect—the elasticity of the penstock and the inertia of the water column. Consequently, standard PID controllers often result in excessive overshoot or slow settling times.

Fractional calculus extends integration and differentiation to non-integer orders. By applying a FOPID controller ($PI^\lambda D^\mu$), the control parameters expand from three to five, allowing for exact shaping of the dynamic response and improved robustness against system uncertainties.

2. Mathematical Modeling

To establish the control loop, we first model the physical plant (penstock, turbine, and generator) and then define the fractional controller.

2.1 The Hydro-Turbine Plant Model

Assuming an ideal water hammer model for a foundational linear approximation, the transfer function relating the mechanical torque to the guide vane deviation is:

$$G_t(s) = e_y \frac{1 - T_w s}{1 + 0.5 T_w s}$$

where T_w is the water starting time constant, and e_y is the partial derivative of turbine torque with respect to the guide vane opening. The numerator $1 - T_w s$ dictates the inverse initial response of the system. The generator dynamics, relating turbine torque to relative speed deviation, are modeled as a first-order inertial element:

$$G_g(s) = \frac{1}{T_a s + e_n}$$

where T_a is the mechanical time constant and e_n is the self-regulation coefficient. The complete plant model is $G_p(s) = G_t(s)G_g(s)$.

2.2 The FOPID Controller

For engineering applications, the Caputo fractional derivative is used because its initial conditions align with integer-order physics. Assuming zero initial conditions, the Laplace transform of a Caputo derivative of order α simplifies to $s^\alpha F(s)$. Applying this to the control law, the transfer function of the FOPID controller is:

$$C(s) = K_p + \frac{K_i}{s^\lambda} + K_d s^\mu$$

where K_p, K_i, K_d are the proportional, integral, and derivative gains, and $\lambda, \mu > 0$ are the continuous fractional orders. This provides two additional tuning knobs (λ and μ) to stabilize the complex plant model $G_p(s)$.

3. Computational Approximation of Fractional Operators

A fundamental challenge in digital control is that the fractional operators s^λ and s^μ represent infinite-dimensional linear filters. They cannot be computed directly by standard microprocessors. Therefore, continuous rational polynomial approximations are required. To implement $C(s)$ computationally, we apply Oustaloup's Recursive Approximation. This method approximates the fractional operator s^α (where $0 < \alpha < 1$) within a specified functional frequency band $[w_b, w_h]$ using an integer-order rational transfer function:

$$s^\alpha \approx K \prod_{k=1}^N \frac{s + w'_k}{s + w_k}$$

where the poles w_k , zeros w'_k , and gain K

are strictly determined by the chosen order N and the frequency boundaries. By selecting a sufficiently high order (e.g., $N=5$), the approximation accurately mirrors the fractional behavior. This translates the abstract fractional calculus into a discrete polynomial format that can be directly optimized and deployed in digital turbine governors.

4. Conclusion

Replacing standard PID controllers with fractional-order variants provides the mathematical flexibility required to tame the chaotic fluid dynamics of hydro-turbines. By utilizing robust polynomial approximations, these advanced fractional models can bridge the gap between theoretical mathematics and applied digital transformation in modern energy grids.

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ЭКВИВАЛЕНТНОСТЬ СЧЁТНЫХ СИСТЕМ ПУТЕЙ ОТНОСИТЕЛЬНО ДЕЙСТВИЯ ПСЕВДООРТОГОНАЛЬНОЙ ГРУППЫ

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Аннотация. В данной работе рассматривается задача об эквивалентности конечных систем путей для действия псевдо ортогональной группы и дается полное решение этой задачи с помощью теории дифференциальных инвариантов.

Пусть G - подгруппа в группе $GL(n, C)$. Две счётных системы путей $\{x^i(t)\}_{i=1}^{\infty}$ и $\{y^i(t)\}_{i=1}^{\infty}$ называются G - эквивалентными, если существует такое $g \in G$, что $y^i(t) = g x^i(t)$ при любых $t \in [0, 1]$, $i = \{1, 2, 3, \dots\}$.

Рассмотрим счётную систему путей $\{x^i(t)\}_{i=1}^{\infty}$ в E , для которой один путь является регулярным. Не ограничивая общности, всегда можно считать, что путь $x^1(t)$ - регулярен. Такие системы путей будем называть определенными.

Следующая теорема дает необходимые и достаточные условия для $O(p, q)$ - эквивалентности определенных систем путей на языке матриц $M(x)(t)$.

Теорема. Две определенные счётных системы путей $\{x^i(t)\}_{i=1}^{\infty}$ и $\{y^i(t)\}_{i=1}^{\infty}$ в E являются $O(p, q)$ - эквивалентными тогда и только тогда, когда выполнены следующие равенства:

$$1) \left(M(x^1(t))\right)^{-1} M'(x^1(t)) = \left(M(y^1(t))\right)^{-1} M'(y^1(t)); \quad (1)$$

$$2) M^T(x^1(t)) I M(x^1(t)) = M^T(y^1(t)) I M(y^1(t)); \quad (2)$$

$$3) \left(M(x^1(t)) \right)^{-1} x^i(t) = \left(M(y^1(t)) \right)^{-1} y^i(t), \quad (3)$$

для всех $t \in [0,1]$, $i = \{2,3,\dots\}$.

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ABOUT GAUSSIAN TORSION OF THE TWO DIMENSIONAL SURFACES

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Abstract: This work investigates the Gaussian torsion of the two-dimensional surface in the four-dimensional Euclidean space. One of the main problems of modern geometry is the embedding of surfaces. The solution of this problem is connected with the surface's Gaussian torsion. That is, we will study the Gaussian torsion of the surfaces with the following equations in R^4 with the coordinates (x, y, z, t)

$$\begin{cases} x = u, \\ y = v, \\ z = f(u), \\ t = g(v). \end{cases}$$

Key words: Gaussian torsion, two-dimensional surface in the four-dimensional Euclidean space, indicatrix of the normal curvature.

Let us recall a notion of Gaussian torsion of a two dimensional surface in four dimensional Euclid space.

Through a point $x_0 \in L$ in some tangent direction τ we draw a curve γ lying on L . Let s be the length of the arc on γ .

Consider the curvature vector k of the curve $\gamma: k = r_{ss}$.

The normal curvature vector k_N of a surface F_n in the direction τ at a point x_0 is called the projection of the curvature vector k of a curve γ onto the normal space N_{x_0} .

The *indicatrix of the normal curvature* of a submanifold at a point x_0 is the set of points N_{x_0} of the endpoints of the normal curvature vectors $k_N(\tau)$, taken for each tangent direction τ and plotted from the point x_0 .

The indicatrix of the normal curvature is an ellipse. Let us denote by a, b the half axis of the *indicatrix of the normal curvature*.

We define the Gaussian torsion σ_G of a two-dimensional surface in four-dimensional space as [2]

$$\sigma_G = 2ab.$$

The Gaussian torsion of a parametrically represented two-dimensional regular surface in a four-dimensional Euclidean space is calculated by formula [1].

$$\sigma_G = \frac{\langle (n_1)_u, (n_2)_v \rangle - \langle (n_1)_v, (n_2)_u \rangle}{\sqrt{g_{11}g_{22} - g_{12}^2}}. \quad (1)$$

which we shall use.

To calculate Gaussian torsion of the surfaces, we need the following tangent vectors

$$r_u = \frac{\partial r}{\partial u} = (1, 0, f'(u), 0), r_v = \frac{\partial r}{\partial v} = (0, 1, 0, g'(v)),$$

and normal vectors

$$n_1 = (-f'(u), 0, 1, 0), n_2 = (0, -g'(v), 0, 1).$$

We know g_{ij} are the first quadratic forms coefficients, in our case

$$g_{11} = E = 1 + (f'(u))^2, g_{12} = F = 0, g_{22} = G = 1 + (g'(v))^2, \\ \sqrt{g_{11}g_{22} - g_{12}^2} = \sqrt{(1 + (f'(u))^2)(1 + (g'(v))^2)}.$$

In the end, we get the following.

$$\sigma_G = \frac{\langle (n_1)_u, (n_2)_v \rangle}{\sqrt{(1 + (f'(u))^2)(1 + (g'(v))^2)}} = 0$$

Theorem 1. The regular surface with the equations

$$\begin{cases} x = u, \\ y = v, \\ z = f(u), \\ t = g(v). \end{cases}$$

is a two-dimensional surface with zero Gaussian torsion in the four-dimensional Euclidean space.

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ON THE GAUSSIAN TORSION OF THE ROTATING SURFACES IN THE FOUR-DIMENSIONAL EUCLIDEAN SPACE

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Abstract: This work investigates the Gaussian torsion of the two-dimensional surface in the four-dimensional Euclidean space. One of the main problems of modern geometry is the embedding of surfaces. The solution of this problem is connected with the surface's Gaussian torsion. That is, we will study the Gaussian torsion of the surfaces with the following equations in R^4 with the coordinates (x, y, z, t)

$$\begin{cases} x = f(u), \\ y = g(u), \\ z = h(u)\cos v, \\ t = h(u)\sin v. \end{cases}$$

Key words: Gaussian torsion, two-dimensional surface in the four-dimensional Euclidean space, indicatrix of the normal curvature.

Let us recall a notion of Gaussian torsion of a two dimensional surface in four dimensional Euclid space.

Through a point $x_0 \in L$ in some tangent direction τ we draw a curve γ lying on L . Let s be the length of the arc on γ .

Consider the curvature vector k of the curve $\gamma : k = r_{ss}$.

The normal curvature vector k_N of a surface F_n in the direction τ at a point x_0 is called the projection of the curvature vector k of a curve γ onto the normal space N_{x_0} .

The indicatrix of the normal curvature of a submanifold at a point x_0 is the set of points N_{x_0} of the endpoints of the normal curvature vectors $k_N(\tau)$, taken for each tangent direction τ and plotted from the point x_0 .

The indicatrix of the normal curvature is an ellips. Let us denote by a, b the half axis of the indicatrix of the normal curvature.

We define the Gaussian torsion σ_G of a two-dimensional surface in four-dimensional space as [2]

$$\sigma_G = 2ab.$$

The Gaussian torsion of a parametrically represented two-dimensional regular surface in a four-dimensional Euclidean space is calculated by formula [1].

$$\sigma_G = \frac{\langle (n_1)_u (n_2)_v \rangle - \langle (n_1)_v (n_2)_u \rangle}{\sqrt{g_{11}g_{22} - g_{12}^2}}. \quad (1)$$

which we shall use.

To calculate Gaussian torsion of the surfaces, we need the following tangent vectors

$r_u = \{f'(u), g'(u), h'(u)\cos v, h'(u)\sin v\}$, $r_v = \{0, 0, -h(u)\sin v, h(u)\cos v\}$,
and normal vectors

$$n_1 = \{-g'(u), f'(u), 0, 0\}, n_2 = \{h'f', h'g', -(f'^2 + g'^2)\cos v, -(f'^2 + g'^2)\sin v\}.$$

We know g_{ij} are the first quadratic forms coefficients, in our case

$$g_{11} = E = f'^2 + g'^2 + h'^2, g_{12} = F = 0, g_{22} = G = h^2(u), \sqrt{g_{11}g_{22} - g_{12}^2} = h\sqrt{f'^2 + g'^2 + h'^2}.$$

In the end, we get the following vectors, which we use to calculate the Gaussian torsion

$$\begin{aligned} n_{1u} &= \{-g''(u), f''(u), 0, 0\}, n_{1v} = \{0, 0, 0, 0\}, \\ n_{2u} &= \{h''f' + h'f'', h''g' + h'g'', -2(f'f'' + g'g''\cos v, -2(f'f'' + g'g'')\sin v\}, \\ n_{2v} &= \{0, 0, (f'^2 + g'^2)\sin v, -(f'^2 + g'^2)\cos v\}. \end{aligned}$$

Theorem. The rotating surface with the equations

$$\begin{cases} x = f(u), \\ y = g(u), \\ z = h(u)\cos v, \\ t = h(u)\sin v \end{cases}$$

is a two-dimensional surface with zero Gaussian torsion in the four-dimensional Euclidean space.

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A HYBRID BERNSTEIN-FRACTIONAL LEGENDRE SPECTRAL METHOD FOR HAMILTON-JACOBI-BELLMAN EQUATIONS WITH APPLICATION TO RESOURCE EXTRACTION OPTIMAL CONTROL

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Abstract

This study proposes a hybrid spectral collocation method based on shifted Bernstein polynomials and fractional-order Legendre polynomials for solving Hamilton-Jacobi-Bellman equations arising from stochastic optimal control problems. The shifted Bernstein basis is employed in the time domain, while the fractional-order Legendre basis is used in the state domain to improve flexibility in approximating nonlinear value functions. The method is applied to a stochastic resource extraction optimal control problem, where the optimal extraction strategy is characterized through the corresponding HJB equation. Numerical results show that the proposed method accurately approximates the value function and optimal control while maintaining lower computational cost than a related shifted Legendre-fractional Legendre scheme.

Keywords: Hamilton-Jacobi-Bellman equation, stochastic optimal control, spectral collocation method, shifted Bernstein polynomials, fractional-order Legendre polynomials, resource extraction problem.

Main Text

Hamilton-Jacobi-Bellman equations play a central role in optimal control theory, particularly in characterizing value functions and optimal feedback policies for deterministic and stochastic control problems. In stochastic systems, the HJB equation is generally nonlinear and contains second-order derivative terms arising from the diffusion component of the underlying stochastic differential equation. Consequently, analytical solutions are rarely available, especially for models involving nonlinear dynamics, uncertain disturbances, and state-dependent control mechanisms.

One important application of stochastic optimal control is the resource extraction problem. This problem describes the decision-making process in managing finite or renewable resources under uncertainty. The control variable represents the extraction rate, while the state variable denotes the remaining resource stock. A major challenge in this problem is to determine an optimal policy that balances short-term economic benefit and long-term resource sustainability.

To address this challenge, a reliable numerical scheme is required. Spectral methods are known for high-order accuracy and rapid convergence when approximating smooth solutions. However, the performance of a spectral method depends strongly on the choice of basis functions. In this study, a hybrid spectral framework is developed by combining shifted Bernstein polynomials in the time domain and fractional-order Legendre polynomials in the state domain. This combination is intended to provide stable temporal approximation and flexible state-space representation for nonlinear HJB equations arising in stochastic optimal control.

Objective and Research Tasks

The main objective of this study is to develop and evaluate a hybrid Bernstein-fractional Legendre spectral collocation method for solving Hamilton-Jacobi-Bellman equations associated with stochastic resource extraction optimal control problems. The specific research tasks are as follows:

Formulate the stochastic resource extraction problem as a stochastic optimal control problem.

Derive the corresponding Hamilton-Jacobi-Bellman equation and optimal feedback control.

Construct a hybrid spectral approximation using shifted Bernstein polynomials in time and fractional-order Legendre polynomials in the state variable.

Transform the HJB equation into a system of nonlinear algebraic equations through spectral collocation.

Compare the numerical performance of the proposed method with a shifted Legendre-fractional Legendre approach.

Analyze the accuracy, convergence behavior, and computational efficiency of the proposed scheme.

Methodology

The study begins by considering a stochastic optimal control problem governed by a stochastic differential equation. The objective functional represents the expected payoff obtained from resource extraction over a finite time horizon, including both the running payoff and terminal resource value. By applying Bellman's principle of optimality and Ito's lemma, the stochastic control problem is transformed into a Hamilton-Jacobi-Bellman equation.

The value function is approximated using a hybrid representation of the form $\Phi(t, x)$ approximately equals the double summation of coefficient c_{ij} multiplied by shifted Bernstein basis functions in time and fractional-order Legendre basis functions in the state variable. In this formulation, the shifted Bernstein basis is defined on the time interval $[t_0, t_f]$, while the fractional-order Legendre basis is constructed on the state interval $[a, b]$ using a fractional mapping parameter α . The unknown coefficients are determined by enforcing the residual of the HJB equation at selected collocation points.

For the resource extraction model, the associated HJB equation is reduced by deriving the optimal control from the maximization of the Hamiltonian. A reference solution is then obtained from the reduced system using the classical fourth-order Runge-Kutta method. This reference solution is used to evaluate the absolute error of the proposed shifted Bernstein-fractional Legendre method. The computational performance is further compared with the shifted Legendre-fractional Legendre method to assess accuracy and efficiency.

Results and Discussion

The numerical results demonstrate that the proposed shifted Bernstein-fractional Legendre method is capable of approximating the value function and optimal feedback control for the stochastic resource extraction problem with good accuracy. The error analysis shows that increasing the polynomial degree in the temporal direction significantly improves the approximation accuracy. In particular, when the temporal degree is increased, the absolute error decreases from the order of 10^{-2} to the order of 10^{-5} , indicating a clear spectral convergence pattern.

The comparison with the shifted Legendre-fractional Legendre method shows that both methods produce comparable levels of accuracy for the tested fractional orders. However, the shifted Bernstein-fractional Legendre method requires lower computational time in most cases. This indicates that the use of shifted Bernstein polynomials in the time domain provides a more efficient alternative while maintaining solution accuracy.

The effect of the fractional-order parameter α is also investigated. The results indicate that the proposed method remains stable for different values of α , including $\alpha = 1/4$, $\alpha = 1/6$, and $\alpha = 1/8$. This suggests that the fractional-order Legendre basis provides flexibility in representing the state-dependent structure of the value function without causing significant instability in the numerical solution.

Furthermore, stochastic simulations based on the Euler-Maruyama scheme show that the resulting optimal control strategy is able to regulate the resource extraction process effectively. The controlled resource stock remains bounded under stochastic perturbations, while the optimal extraction rate decreases gradually over time. This behavior is consistent with the principle of sustainable resource management, where stronger control is required at the early stage and extraction intensity is reduced as the system approaches the terminal horizon.

The scientific novelty of this study lies in the construction of a hybrid spectral collocation framework that combines the stability of shifted Bernstein polynomials and the flexibility of fractional-order Legendre polynomials for solving stochastic HJB equations. From a practical perspective, the proposed method provides an efficient computational tool for analyzing optimal extraction strategies under uncertainty.

Conclusions and Recommendations

This study presents a hybrid shifted Bernstein-fractional Legendre spectral collocation method for solving Hamilton-Jacobi-Bellman equations arising from stochastic resource extraction optimal control problems. The proposed method successfully approximates the value function and optimal control policy with high accuracy and stable convergence behavior. Numerical comparisons

show that the method achieves comparable accuracy to the shifted Legendre-fractional Legendre scheme while requiring lower computational time.

The results confirm that the proposed method is suitable for solving nonlinear stochastic HJB equations, particularly in resource management problems involving uncertainty. For future research, the method can be extended to higher-dimensional HJB equations, adaptive mesh strategies, and other classes of stochastic optimal control problems. Further investigation may also consider combining the proposed hybrid basis with sparse grid or domain decomposition techniques to improve computational efficiency for more complex systems.

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CONDITIONAL WELL-POSEDNESS AND OF THE INITIAL-BOUNDARY VALUE PROBLEM FOR A HELMHOLTZ-TYPE EQUATION

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This work is devoted to the study of conditional well-posedness of the initial-boundary value problem for a helmholtz-type equation.

Let the function $u(x, y)$ is a solution of equation

$$u_{xx}(x, y) + u_{yy}(x, y) + au(x, y) = f(x, y), \quad (1)$$

in the region $Q = \{(x, y) : 0 < x < l, 0 < y < d\}$ and satisfy the initial conditions

$$u(x, 0) = \varphi(x), u_y(x, 0) = \psi(x), \quad 0 \leq x \leq l, \quad (2)$$

the boundary conditions

$$u|_{x=0} = 0, u|_{x=l} = 0, \quad 0 \leq y \leq d, \quad (3)$$

where $\varphi(x), \psi(x)$ are given sufficiently smooth functions defined for $x \in [0, l]$, moreover, $\varphi(0) = \varphi(l)$.

Lemma. Let $u(x, y)$ be a solution of the problem (1)-(4) in the region Q . Then for any $y \in (0, d)$ we have the estimate

$$\int_0^y \|u(x, \tau)\|^2 d\tau \leq \left(\int_0^d \|u(x, y)\|^2 dy + \gamma \right)^{r(y)} \left(d \|u(x, 0)\|^2 + \gamma \right)^{1-r(y)} C(y),$$

$$\text{where } \gamma = (2d^2 + 3) \int_0^d \int_0^l f^2 dx dy + \beta, \quad C(y) = \exp \left((d+1) \frac{(1-e^{-y})d - (1-e^{-d})y}{1-e^{-d}} \right), \quad r(y) = \frac{1-e^{-y}}{1-e^{-d}},$$

$$\beta = 2d \left| \int_0^l (u_x^2(x, 0) - u_y^2(x, 0) - au(x, 0)) dx \right| + 2 \left| \int_0^l u(x, 0) u_y(x, 0) dx \right|.$$

We introduce the set of correctness as follows:

$$M = \left\{ u(x, y) : \int_0^d \|u(x, y)\|^2 dy \leq m^2 \right\}.$$

Theorem 1. Let the solution of the problem (1)–(3) exists and $u(x, y) \in M$. Then the solution of the problem (1)–(3) is unique.

Theorem 2. Let the solution to the problem (1)–(3) exist, such that $u(x, y), u_\varepsilon(x, y) \in M$ and assume the following error bounds hold: $\|f(x, y) - f_\varepsilon(x, y)\| \leq \varepsilon, \|\varphi(x) - \varphi_\varepsilon(x)\|_{W^1_1} \leq \varepsilon, \|\psi(x) - \psi_\varepsilon(x)\| \leq \varepsilon$. Then the following estimate holds:

$$\int_0^y \|u(x, y) - u_\varepsilon(x, y)\|^2 d\tau \leq (2m^2 + \delta(d, \varepsilon, a))^{r(y)} (d\varepsilon^2 + \delta(d, \varepsilon, a))^{1-r(y)} C(y)$$

where $\delta(d, \varepsilon, a) = (2d^3 + 7d + 2da + 2)\varepsilon^2$.

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BESSEL OPERATORINING KVADRATI QATNASHGAN SPEKTRAL CHEGARAVIY MASALA

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Annotatsiya. Mazkur ishda Bessel operatorining kvadrati qatnashgan spektral chegaraviy masalaning xos sonlari va xos funksalari o‘rganilgan. Olingan natijalar matematik fizika masalalari, tebranish jarayonlari, issiqlik tarqalishi, to‘lqin tenglamalari va silindrik-simmetrik muhitlardagi jarayonlarni modellashtirishda qo‘llaniladi.

Ushbu maqolada Bessel operatorining kvadrati qatnashgan 4-tartibli spektral chegaraviy masalani ko‘rib chiqamiz. Bu ko‘rinishdagi masalani Erdey-Kober operatori yordamida yechish ilgari o‘rganilmagan. Quyidagi Shturm-Liuvill masalasini qaraymiz:

$$\begin{aligned} B_{\frac{a}{2}}^2 y &= \lambda y \\ x &\in (0, l), \quad 0 < a < 1 \end{aligned} \tag{1}$$

$$y'(0) = 0, \quad y'''(0) = 0, \quad {}^{EK}D_{0x}^{\frac{a}{2}} y(x) \Big|_{x=l} = 0, \quad \frac{d^2}{dx^2} {}^{EK}D_{0x}^{\frac{a}{2}} y(x) \Big|_{x=l} = 0 \tag{2}$$

Bu yerda $B_{\frac{a}{2}} = \frac{d^2}{dx^2} + \frac{a}{x} \frac{d}{dx}$ - Bessel operatori, ${}^{EK}D_{0x}^{\frac{a}{2}} y \Big|_{x=l} = I_{-\frac{1}{2}, \frac{a}{2}}^{-1} y =$

$$= \frac{1}{\Gamma\left(1 - \frac{a}{2}\right)} \int_0^1 (1-s^2)^{-\frac{a}{2}} s^a [xy(xs)]' ds - \text{teskari Erdey-Kober operatori.}$$

(1) tenglamadagi y ni Erdey-Kober operatori yordamida quyidagi ko‘rinishda qidiramiz

$$y(x) = I_{-\frac{1}{2}, \frac{a}{2}} z(x) = \frac{2}{\Gamma\left(\frac{a}{2}\right)} \int_0^1 (1-t^2)^{\frac{a}{2}-1} z(tx) dt \tag{3}$$

(3) belgilashni (1) tenglamaga qo'yish natijasida

$$\left(\frac{d^2}{dx^2} + \frac{a}{x} \frac{d}{dx}\right)^2 I_{\frac{1}{2}, \frac{a}{2}} z(x) - \lambda I_{\frac{1}{2}, \frac{a}{2}} z(x) = 0 \quad (4)$$

tenglamaga keladi. (4) tenglamadan butun tartibli Bessel va Erdey-Kober operatorlari kombinatsiyasini ko'rib chiqamiz:

Teorema. ([1]) $z(x) \in C^{2m}(0, b)$, $b > 0$, $\alpha > 0$, $\eta \geq -\frac{1}{2}$ bo'lsin, $x^{2\eta+1} [B_\eta^x]^{k+1} z(x)$ funksiyalar nol atrofida integrallanuvchi va $\lim_{x \rightarrow 0} x^{2\eta+1} \left(\frac{d}{dx}\right) [B_\eta^x]^k z(x) = 0$, $k = \overline{0, m-1}$ bo'lsa u holda quyidagi tenglik o'rinli bo'ladi

$$[B_{\eta+\alpha}^x]^m I_{\eta, \alpha} z(x) = I_{\eta, \alpha} [B_\eta^x]^m z(x)$$

Yuqoridagi teorema ko'ra $m = 2$, $\eta = -\frac{1}{2}$, $\lim_{x \rightarrow 0} x^{2\eta+1} \left(\frac{d}{dx}\right) [B_\eta^x]^k z(x) = 0$,

$k = \overline{0, m-1}$, $z(x) \in C^{2m}(0, b)$ ya'ni $\lim_{x \rightarrow 0} \frac{d}{dx} \frac{d^{2k}}{dx^{2k}} z(x) = \lim_{x \rightarrow 0} \frac{d^{2k+1}}{dx^{2k+1}} z(x) = 0$, $k = 0, 1$ ekanligi kelib

chiqadi. $k = 0$, $\lim_{x \rightarrow 0} \frac{dz(x)}{dx} = z'(0) = 0$ va $k = 1$, $\lim_{x \rightarrow 0} \frac{d^3 z(x)}{dx^3} = z'''(0) = 0$ shartlar (2) chegaraviy shartlar bilan o'xshash. Natijada quyidagi ko'rinishdagi tenglama kelib chiqadi: $I_{\frac{1}{2}, \frac{a}{2}} (z^{(4)}(x) + (-\lambda) z(x)) = 0$

Yuqoridagilardan quyidagi z ga bog'liq chegaraviy masalaga kelimiz:

$$z^{(4)}(x) - \lambda z(x) = 0 \quad (5)$$

$$z'(0) = z'''(0) = 0, \quad z(l) = z''(l) = 0 \quad (6)$$

Aniqlanish sohasi quyidagicha $D_A = \{z : z'(0) = z'''(0) = 0, z(l) = z''(l) = 0\}$ bo'lgan $A \equiv \frac{d^4}{dx^4}$

operatorini tatbiq etamiz. Avvalo bu operatorning musbatligi, ya'ni $(Az, z) > 0$ ekanligini ko'rsatamiz.

$$\begin{aligned} (Az, z) &= \int_0^l z \cdot Az dx = \int_0^l z \cdot z^{(4)} dx = \int_0^l z dz^{(3)} = z z^{(3)} \Big|_0^l - \int_0^l z^{(3)} z' dx = z z^{(3)} \Big|_0^l - \int_0^l z' dz'' = \\ &= z z^{(3)} \Big|_0^l - z' z'' \Big|_0^l + \int_0^l (z'')^2 dx > 0. \quad Az = \lambda z \quad \text{tenglamadan} \quad (Az, z) = (\lambda z, z) = \lambda (z, z) = \lambda \|z\|^2, \quad \text{ya'ni} \end{aligned}$$

$\lambda = \frac{(Az, z)}{\|z\|^2} > 0$ ekanligi kelib chiqadi. (5)-(6) masalaning xos sonlari mavjud bo'lsa uning musbat

ekanligi kelib chiqadi. Yuqoridagi operatorni simmetriklikka tekshiramiz: $(Az_1, z_2) = (z_1, Az_2)$,

$$\begin{aligned} (Az_1, z_2) &= \int_0^l z_1^{(4)} z_2 dx = z_1'' z_2' \Big|_0^l - \int_0^l z_1'' z_2' dx = z_1'' z_2' \Big|_0^l - z_1' z_2'' \Big|_0^l + \int_0^l z_1' z_2'' dx = \\ &= z_1'' z_2' \Big|_0^l - z_1' z_2'' \Big|_0^l + z_1' z_2'' \Big|_0^l - \int_0^l z_1' z_2''' dx = z_1'' z_2' \Big|_0^l - z_1' z_2'' \Big|_0^l + z_1' z_2'' \Big|_0^l - z_1 z_2^{(4)} \Big|_0^l + \int_0^l z_1 z_2^{(4)} dx = \int_0^l z_1 z_2^{(4)} dx = (z_1, Az_2). \end{aligned}$$

Ushbu operatorni ortogonallikka tekshiramiz: $Az_1 = \lambda_1 z_1$, $Az_2 = \lambda_2 z_2$,

$$\lambda_1 (z_1, z_2) = (\lambda_1 z_1, z_2) = (Az_1, z_2) = (z_1, Az_2) = (z_1, \lambda_2 z_2) = \lambda_2 (z_1, z_2), \quad (\lambda_1 - \lambda_2)(z_1, z_2) = 0, \quad \lambda_1 \neq \lambda_2$$

Qulaylik uchun (5) tenglamada $\lambda = \zeta^4$ belgilash ishlataylik. (5) tenglamaning umumiy yechimi $z(x) = C_1 e^{\zeta x} + C_2 e^{-\zeta x} + C_3 \cos \zeta x + C_4 \sin \zeta x$ bo'lib (6) chegaraviy shartlarni inobatga olish natijasida $\zeta_k = \left(\frac{2k+1}{2l}\right)\pi$, $k \in \mathbb{Z}$ bundan $\lambda_k = (\zeta_k)^4 = \left[\left(\frac{2k+1}{2l}\right)\pi\right]^4$, $k \in \mathbb{Z}$ xos son va $z_k(x) = C_3 \cos\left(\frac{2k+1}{2l}\pi x\right)$, $k \in \mathbb{Z}$ xos funksiyalarni olamiz. (3) formulaga ko'ra $y_k(x) = I_{-\frac{1}{2}, \frac{a}{2}} z_k(x) = \frac{2}{\Gamma\left(\frac{a}{2}\right)} \int_0^1 (1-t^2)^{\frac{a}{2}-1} \cos\left(\frac{2k+1}{2l}\pi t\right) \pi t x dt$.

Puasson integrali formulasiga ko'ra ([2]) $\Gamma\left(\nu + \frac{1}{2}\right) J_\nu(z) = \frac{2}{\sqrt{\pi}} \left(\frac{z}{2}\right)^\nu \int_0^1 (1-t^2)^{\nu-\frac{1}{2}} \cos(zt) dt$ tenglik o'rinli. Bundan xos funksiyalar quyidagicha ekanligi kelib chiqadi:

$$y_k(x) = \frac{2}{\Gamma\left(\frac{a}{2}\right)} \int_0^1 (1-t^2)^{\frac{a}{2}-1} \cos\left[\left(\frac{2k+1}{2l}\pi x\right)t\right] dt = \pi^{\frac{1-a}{2}} \left(\frac{2k+1}{4l}x\right)^{\frac{1-a}{2}} J_{\frac{a-1}{2}}\left(\frac{2k+1}{2l}\pi x\right). \quad \text{Bu yerda}$$

$J_\nu(x) = \sum_{n=0}^{\infty} \frac{(-1)^n \left(\frac{x}{2}\right)^{2n+\nu}}{\Gamma(n+1)\Gamma(n+\nu+1)}$ funksiya birinchi turdagi ν indeksli yoki ν tartibli Bessel funksiyalari deyiladi.([3]).

Adabiyotlar

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GALILEY FAZOSIDA PARALLEL SIRTSLAR VA ULARNING GEOMETRIYASI

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Ushbu maqola uch o'lchovli Galiley fazosida parallel sirtlarning differensial xossalari va ularning geometrik xarakteristikalarini o'rganishga bag'ishlangan. Maqolada parallel sirtlar asosiy sirtga bog'liq holda o'rganilgan bo'lib, dastlab parallel sirt tushunchasi kiritilgan. Shuningdek, parallel sirtlarning asosiy xususiyatlari, jumladan, birinchi va ikkinchi kvadratik formalari, normal egrilik, to'la egrilik va o'rta egrilik kabi tushunchalar tahlil qilingan. Maqolaning asosiy qismida parallel sirtlar uchun birinchi va ikkinchi kvadratik formalarning koeffitsiyentlari topilib, normal egrilik, to'la egrilik va o'rta egrilik formulalari isbotlangan. Bundan tashqari, parallel sirtlar orasidagi masofa va ularning o'zaro joylashuvi tahlil qilingan.

Geometriyaning asosiy tushunchalaridan biri bo'lgan **sirtlar nazariyasi** turli sohalarda, jumladan, differensial geometriya, fizika, muhandislik va matematik modellashirishda keng qo'llaniladi. Sirtlarning xossalari va ularning o'zaro bog'lanishlarini o'rganish, ayniqsa, maxsus geometrik fazolarda, masalan, **Galiley fazosida**, alohida ahamiyatga ega. Galiley fazosi – bu

nisbiylik nazariyasi va klassik mexanikada muhim rol o'ynaydigan geometrik struktura bo'lib, unda vaqt va makonning o'ziga xos bog'lanishlari o'rganiladi.

A.Artikbaev va N.Ye.Pankina birinchi bo'lib Galiley fazosida to'la geometriya muammolarini o'ziga xos hal qilish bilan shug'ullangan [1,2]. Shuningdek, O.Roshel monografiyasida uch o'lchamli Galiley fazosining nazariyasi tasvirlangan [3]. Keyinchalik esa Galiley fazosida sirt nazariyasiga bag'ishlangan ko'plab maqolalar yozilgan va bu ishlarda Galiley fazosining differensial geometriyasi o'rganilgan [4-6].

Uch o'lchovli affin fazo A_3 , koordinatalar boshi $O(0,0,0)$ nuqtada bo'lgan $Oxyz$ affin koordinatalar sistemasi va $\{\vec{i}, \vec{j}, \vec{k}\}$ – bu fazoning bazis vektorlari bo'lsin.

Berilgan $\vec{X}\{x_1, y_1, z_1\}$ va $\vec{Y}\{x_2, y_2, z_2\}$ vektorlarning skalyar ko'paytmasi quyidagi formula bilan kiritilsin

$$(\vec{X}\vec{Y}) = \begin{cases} x_1x_2, \text{ agar } x_1x_2 \neq 0, \\ y_1y_2 + z_1z_2, \text{ agar } x_1x_2 = 0. \end{cases} \quad (1)$$

1-ta'rif. $\vec{X}\{x_1, y_1, z_1\}$ va $\vec{Y}\{x_2, y_2, z_2\}$ vektorlarning skalyar ko'paytmasi (1) formula bilan aniqlangan affin fazo Galiley fazosi deyiladi va R_3^1 yoki G_3 bilan belgilanadi [7].

Galiley fazosida

$$\vec{r} = \vec{r}(u, v) = u\vec{i} + y(u, v)\vec{j} + z(u, v)\vec{k}, \quad (2)$$

ko'rinishda bo'ladi [7].

Faraz qilaylik, bizga uch o'lchovli Galiley fazosida M sirt berilgan bo'lib, uning tenglamasi (2) ko'rinishda bo'lsin. Bu sirt uchun birlik normal tenglamasi quyidagicha:

$$n = \frac{[r_u, r_v]}{[r_u, r_v]} = \frac{-z_v e_2 + y_v e_3}{\sqrt{G}},$$

bo'ladi. Bu yerda $[r_u, r_v] = \sqrt{y_v^2 + z_v^2} = \sqrt{G}$.

Sirtning birinchi kvadatik formasi:

$$ds^2 = I_1 = du^2.$$

Agar $I_1 = 0$ bo'lsa, egri chiziqliq maxsus tekislikda yotadi. U holda

$$ds^2 = I_2 = (y_v^2 + z_v^2)dv^2 = Gdv^2,$$

ko'rinishda bo'ladi. I_2 ga sirtning qo'shimcha birinchi kvadratlik formasi deyiladi.

Ushbu ifodaga

$$II = (d^2 \vec{r} \vec{n}) = Ldu^2 + 2Mdudv + Ndv^2,$$

sirtning ikkinchi kvadratlik formasi deyiladi. Bu yerda

$$L = (r_{uu} \vec{n}) = \frac{-y_{uu}z_v + z_{uu}y_v}{\sqrt{G(u, v)}}, M = (r_{uv} \vec{n}) = \frac{-y_{uv}z_v + z_{uv}y_v}{\sqrt{G(u, v)}}, N = (r_{vv} \vec{n}) = \frac{-y_{vv}z_v + z_{vv}y_v}{\sqrt{G(u, v)}}$$

Sirt uchun to'la va o'rta egriliklarni birinchi va ikkinchi kvadratlik formalardan foydalanib topamiz:

$$K = \frac{LN - M^2}{G} = \frac{(y_{uv}^2 + y_{uu}y_{vv})z_v^2 - (y_{uu}z_{vv} + y_{vv}z_{uu} - 2y_{vv}z_{uv})y_vz_v + (z_{uu}z_{vv} - z_{uv}^2)y_v^2}{G^2}$$

$$H = \frac{N}{2} = \frac{y_{vv}z_v - z_{vv}y_v}{2\sqrt{G}}$$

Bunda, K - to'la egrilik va H - o'rta egriliklar deyiladi.

Yuqoridagi natijalardan kelib chiqib quyidagi munosabatlarni ham topishimiz mumkin:

$$\begin{aligned}\vec{r}_{uu} &= \Gamma_{11}^2 \vec{r}_v + L \vec{r}, \quad \vec{r}_{uv} = \Gamma_{21}^2 \vec{r}_v + M \vec{n}, \quad \vec{r}_{vv} = \Gamma_{22}^2 \vec{r}_v + N \vec{n} \\ \vec{n}_u &= -\frac{M}{G} \vec{r}_v, \quad \vec{n}_v = -\frac{N}{G} \vec{r}_v\end{aligned}$$

Γ_{ij}^2 -miqdorlari Kristoffel ko'effitsientlari analogi hisoblanib, quyidagi ko'rinishga ega:

$$\Gamma_{11}^2 = \frac{F_u - \frac{1}{2}E_v}{G}, \quad \Gamma_{21}^2 = \frac{G_u}{2G}, \quad \Gamma_{22}^2 = \frac{G_v}{2G}$$

Bu yerda: $F = y_u y_v + z_u z_v$, $E = y_u^2 + z_u^2$.

Galiley fazosi G_3 da M va M^λ ikkita sirt berilgan bo'lsin.

2-ta'rif: Quyidagi funksiya

$$\begin{aligned}f: r(u, v) &\rightarrow r^\lambda(u, v) \\ p &\rightarrow f(p) = [p_1; p_2 + \lambda a_2(p); p_3 + \lambda a_3(p)]\end{aligned}$$

M va M^λ sirtlar orasidagi parallellashtirish funksiyasi deyiladi.

Bu yerda, $p = (p_1, p_2, p_3)$ va $n = (0, a_2, a_3)$. n ga M sirtidagi birlik normal, M^λ ga G_3 fazoda M sirtga parallel sirt deyiladi, λ esa berilgan haqiqiy musbat son.

Ma'lumki, umumiy normalga ega sirlarga parallel sirtlar deyiladi. Bundan quyidagi ta'rifni berishimiz mumkin.

Galiley fazosida M va M^λ sirtlar berilgan bo'lsin.

3-ta'rif: Quyidagi

$$r^\lambda(u, v) = r(u, v) + \lambda n$$

funksiyaga λ masofada M sirtga parallel bo'lgan M^λ sirt tenglamasi deyiladi.

Yuqorida berilgan ta'riflardan ravshanki, biz M^λ parallel sirtni bevosita asosiy sirt M ga bog'liq holda o'rganamiz.

M va M^λ Galiley fazosidagi parallel sirtlar bo'lsin.

1-teorema: Parallel sirt uchun birinchi kvadratik forma I^λ quyidagicha:

$$ds^2 = I_1^\lambda = du^2,$$

agar $I_1^\lambda = 0$ bo'lsa, u holda

$$ds^2 = I_2^\lambda = \left(\frac{(G - \lambda N)^2}{G} + (\Gamma_{22}^2)^2 \lambda^2 \right) dv^2 = G^\lambda dv^2$$

bo'ladi

2-teorema: Parallel sirt uchun ikkinchi kvadratik forma ko'effitsiyentlari quyidagicha:

$$L^\lambda = \frac{L(G - \lambda N)}{G} + \Gamma_{11}^2 \Gamma_{22}^2 \lambda, \quad M^\lambda = \frac{M(G - \lambda N)}{G} + \Gamma_{21}^2 \Gamma_{22}^2 \lambda, \quad N^\lambda = \frac{N(G - \lambda N)}{G} + (\Gamma_{22}^2)^2 \lambda$$

bo'ladi.

3-teorema: M^λ parallel sirt uchun normal egrilik quyidagicha:

$$k_n^\lambda = \frac{II^\lambda}{I^\lambda} = \frac{L^\lambda du^2 + 2M^\lambda dudv + N^\lambda dv^2}{ds^2}$$

bo'ladi.

4-teorema: M^λ parallel sirt uchun to'la egrilik quyidagicha:

$$K^\lambda = \frac{(G - N\lambda)^2 K + (G - N\lambda) \left((\Gamma_{22}^2)^2 L + \Gamma_{11}^2 \Gamma_{22}^2 N - 2\Gamma_{21}^2 \Gamma_{22}^2 M \right) \lambda}{(G - N\lambda)^2 + (\Gamma_{22}^2)^2 G \lambda^2} +$$

$$+ \frac{(GK - N) N \lambda + \left((\Gamma_{22}^2)^3 \Gamma_{11}^2 - (\Gamma_{22}^2 \Gamma_{11}^2)^2 \right) \lambda^2}{(G - N\lambda)^2 + (\Gamma_{22}^2)^2 G \lambda^2}$$

ko‘rinishda bo‘ladi.

5-Teorema: M^λ parallel sirt uchun o‘rta egrilik quyidagicha:

$$H^\lambda = \frac{N^\lambda}{2} = \frac{1}{2} \left(\frac{N}{G} \frac{G - \lambda N}{G} + \Gamma_{22}^2 \lambda \right)$$

bo‘ladi.

Ushbu maqolada uch o‘lchovli **Galiley fazosida parallel sirtlarning geometriyasi** o‘rganildi. Parallel sirtlar uchun birinchi va ikkinchi kvadratik formalarning koeffitsiyentlari aniqlanib, ularning asosiy sirt bilan bog‘lanishi ko‘rsatildi. Parallel sirtlarning normal, to‘la va o‘rta egriliklari hisoblab chiqildi va ularning formulalari isbotlandi. Shuningdek, parallel sirtlar orasidagi geometrik bog‘lanishlar tahlil qilinib, ularning o‘zaro joylashuvi va masofasi haqida tushunchalar berildi.

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О РАЗРЕШИМОСТИ ОДНОЙ КРАЕВОЙ ЗАДАЧИ ДЛЯ УРАВНЕНИЯ ЧЕТВЕРТОГО ПОРЯДКА В ПРЯМОУГОЛЬНОЙ ОБЛАСТИ

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Аннотация: В данной работе для уравнения четвертого порядка в прямоугольной области рассмотрена краевая задача. Доказана однозначная разрешимость и устойчивость решения задачи.

Ключевые слова: уравнение четвертого порядка, метод разделения переменных, единственность, существование, устойчивость решения.

Краевые задачи для дифференциальных уравнений четвертого порядка играют важную роль в математическом моделировании процессов механики сплошных сред и прикладной физики. Такие уравнения возникают при исследовании динамики сжимаемой экспоненциально стратифицированной жидкости, распространения волн в диспергирующих средах, вибраций судовых конструкций, а также при описании колебаний стержней, балок и пластин. В данной работе для уравнения четвертого порядка в прямоугольной области

рассмотрена граничная задача. Решение задачи построено в виде суммы ряда по собственным соответствующей спектральной задачи.

В области $\Omega = \{(x, y): 0 < x < 1, 0 < y < q\}$ рассмотрим уравнение

$$Lu \equiv u_{yyy} + u_y - u_{xxxx} - b^2 u = f(x, y)$$

где $b = \text{const}$, $f(x, y)$ - заданная достаточно гладкая функция.

Задача 1. Найти в области Ω функцию $u(x, y)$ удовлетворяющие условиям

$$u(x, y) \in C_{x,y}^{3,1}(\bar{\Omega}) \cap C_{x,y}^{4,3}(\Omega);$$

$$Lu(x, y) \equiv f(x, y), (x, y) \in \Omega;$$

$$u(x, 0) = \varphi(x), u_y(x, 0) = \psi(x), u(x, q) = \eta(x), 0 \leq x \leq 1;$$

$$u(1, y) = 0, u_x(0, y) = -u_x(1, y), u_{xx}(0, y) = 0, u_{xxx}(0, y) = -u_{xxx}(1, y), 0 \leq y \leq q$$

где $\varphi(x), \psi(x), \eta(x)$ - заданные функции, причем $\varphi(1) = \eta(1) = \psi(1) = 0$, $\varphi^{(2i+1)}(0) = -\varphi^{(2i+1)}(1)$, $\eta^{(2i+1)}(0) = -\eta^{(2i+1)}(1)$, $i = 0, 1$; $\varphi''(0) = \eta''(0) = 0$.

Доказана однозначная разрешимость поставленной задачи. Решение задачи построено в виде суммы ряда по собственным соответствующей спектральной задачи. Собственные функции соответствующей спектральной задачи являются полной системой и образуют базис Рисса в пространстве $L_2(0, 1)$ [1]. Единственность решения задачи вытекает из полноты системы собственных функций. В замкнутой области $\bar{\Omega}$ показана абсолютная и равномерная сходимость найденного решения задачи в виде ряда, а также рядов, полученных почленным дифференцированием по y и x соответственно три и четыре раза. Доказана также, устойчивость решения задачи.

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О ПРОДОЛЖЕНИИ РЕШЕНИЙ УРАВНЕНИЙ МАГНИТНОГО ПОЛЯ В НЕОГРАНИЧЕННОЙ ОБЛАСТИ ТИПА СЛОЯ

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Пусть R^3 ($n \geq 3$) – вещественное евклидово пространство,

$$x = (x_1, x_2, x_3), y = (y_1, y_2, y_3) \in R^3, x' = (x_1, x_2), y' = (y_1, y_2) \in R^2,$$

$$s = \alpha^2 = (y_1 - x_1)^2 + (y_2 - x_2)^2, r^2 = |y - x|^2 = \alpha^2 + (y_3 - x_3)^2.$$

В работах [1]–[2] показано, что многие результаты теории плоского геопотенциального поля могут быть распространены на трехмерный случай путем конструирования пространственных аналогов интеграла типа Коши, являющихся модификацией интегралов, введенных Моисилом, Теодореско и Бицадзе [3]. В настоящей работе [4], являющейся обобщением и развитием предыдущих исследований, получены представления трехмерных геопотенциальных полей, обусловленных возмущающими телами с произвольным распределением намагниченности, в виде пространственных аналогов интеграла типа Коши по поверхностям возмущающих тел. Эти представления оказываются чрезвычайно удобными как при решении прямых, так и обратных трехмерных задач магнитометрии.

Рассмотрим трехмерную область Ω , неограниченную с кусочно-гладкой границей $\partial\Omega$ и заполненную магнитными массами с плотностью $\rho(x)$ и намагниченностью $I(x)$ соответственно. В области Ω задано непрерывно дифференцируемая вектор-функция $\vec{F}(x) = (F_1(x), F_2(x), F_3(x))$. При изучении геофизических полей в качестве области существования векторного поля $\vec{F}$ обычно рассматривается все безграничное пространство, а источники и вихри поля полагают локализованными в некоторой конечной области Ω .

Векторное поле F , непрерывно дифференцируемое в области Ω пространства (с границей S) и удовлетворяющее там уравнениям

$$\operatorname{div} F = q, \quad \operatorname{rot} F = j \quad (1)$$

где q, j - объемные плотности источников и вихрей поля F . Зададим вспомогательное векторное поле Ψ [5]:

$$\Psi(r) = -\frac{1}{4\pi} \left\{ (v \cdot F) \operatorname{grad} \frac{1}{|r-r'|} + (v \times F) \times \operatorname{grad} \frac{1}{|r-r'|} - [(v \times \operatorname{rot} F)] \cdot \frac{1}{|r-r'|} \right\},$$

где v - произвольный постоянный вектор r, r' - радиус-векторы переменной M и фиксированной M' точек пространства.

Для этого воспользуемся трехмерной формулой Помпей [5]

$$\begin{aligned} & -\frac{1}{4\pi} \iint_S \{ (\vec{n} \cdot \vec{F}) \operatorname{grad} \Phi_\sigma(y, x) + (\vec{n} \times \vec{F}) \times \operatorname{grad} \Phi_\sigma(y, x) \} dS_y + \\ & + \frac{1}{4\pi} \iiint_D \operatorname{div} \vec{F} \cdot \operatorname{grad} \Phi_\sigma(y, x) dv = \begin{cases} \vec{F}(x), & x \in \Omega, \\ 0, & x \notin \bar{\Omega} \end{cases} \end{aligned} \quad (2)$$

предварительно переписав ее в виде

$$C^s(x, \vec{F}(y)) + \frac{1}{4\pi} \iiint_D \operatorname{div} \vec{F} \cdot \operatorname{grad} \Phi_\sigma(y, x) dv = \begin{cases} 0, & x \notin \Omega, \\ \vec{F}(x), & x \in \Omega \end{cases}$$

$$C^s(x, \vec{F}(y)) = \operatorname{grad}' \left\{ -\frac{1}{4\pi} \iint_S \Phi_\sigma(y, x) q^s dS_y - \frac{1}{4\pi} \iint_S m \cdot \operatorname{grad} \Phi_\sigma(y, x) dS_y \right\},$$

$$q^s = -(\vec{n} \cdot \vec{F}), \quad m^s = -F q^s = -(\vec{n} \cdot \vec{F}), \quad m^s = -F \vec{n}.$$

$$2\pi^2 e^{\sigma x_3^2 + \sigma \alpha^2 - \sigma y_3^2} \cdot \Phi_\sigma(y, x) = \int_0^\infty \frac{\varphi_\sigma(y, x; u)}{u^2 + r^2} e^{-\sigma u^2} du, \quad (3)$$

$$\varphi_\sigma(y, x; u) = \cos \tau \sqrt{u^2 + \alpha^2} - (y_3 - x_3) \frac{\sin \tau \sqrt{u^2 + \alpha^2}}{\sqrt{u^2 + \alpha^2}}, \quad \tau = 2\sigma y_3.$$

Дадим теперь представление магнитного поля $H(r)$ в виде пространственных аналогов интеграла типа Коши по границе области, заполненной намагниченными массами с интенсивностью намагничивания (вектором намагниченности) $I(r)$. Будем предполагать, что $I(r)$ - непрерывно дифференцируема в D . Тогда магнитное поле можно представить в виде

$$\begin{aligned} H(\vec{y}) &= \operatorname{grad}' \iiint_\Omega I(r) \operatorname{grad}' \Phi_\sigma(y, x) dV = \\ &= -\iint_S (\dot{I}(x) \cdot \vec{n}) \operatorname{grad}' \Phi_\sigma(y, x) dS_y + \iiint_\Omega \operatorname{div} \dot{I}(x) \operatorname{grad} \Phi_\sigma(y, x) dS_y \end{aligned} \quad (4)$$

где штрих означает дифференцирование по r' .

Заметим, что поверхностный интеграл в правой части (4) может быть записан так:

$$-\iint_S (I(r) \cdot \vec{n}) \operatorname{grad}' \Phi_\sigma(y, x) dS = C^s(r'; -4\pi I_n(r)), \quad (5)$$

где $I_n(r)$ - нормальная компонента вектора намагниченности на поверхности S .

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О ПРОДОЛЖЕНИИ РЕШЕНИЕ ЗАДАЧИ КОШИ ДЛЯ ОБОБЩЕННОЙ СИСТЕМЫ КОШИ-РИМАНА С КВАТЕРНИОННЫМ ПАРАМЕТРОМ В БЕСКОНЕЧНОЙ ОБЛАСТИ ТИПА СЛОЯ

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Аннотация. В работе получена регуляризованная решения задачи Коши для обобщенной системы Коши-Римана с кватернионным параметром в неограниченной области.

Ключевые слова. Система Коши-Римана, кватернион, некорректная задача, интегральная формула Коши.

Annotation. In this paper, a regularized solution of the Cauchy problem for a generalized Cauchy-Riemann system with a quaternion parameter in an unbounded domain is obtained.

Key words. Cauchy-Riemann system, quaternion, ill-posed problem, Cauchy integral formula.

Пусть Ω - неограниченная односвязная область в R^3 с границей $\partial\Omega$ состоящей из компактной связной части T плоскости $y_3 = 0$ и гладкого куска поверхности S Ляпунова, лежащей в полупространстве $y_3 \geq 0$, $\bar{\Omega} = \Omega \cup \partial\Omega$, $\partial\Omega = S \cup T$, $x = (x_1, x_2, x_3)$, $y = (y_1, y_2, y_3) \in R^3$, $x' = (x_1, x_2, 0)$, $y' = (y_1, y_2, 0) \in R^2$, $s = (y_1 - x_1)^2 + (y_2 - x_2)^2$, $r^2 = |y - x| = s + (y_3 - x_3)^2$.

Рассмотрим систему уравнений [1]

$$\alpha_0 f_0 - \operatorname{div} f - \langle f, \vec{\alpha} \rangle = 0, \quad \operatorname{grad} f_0 + \operatorname{rot} f + [f \times \vec{\alpha}] + f_0 \vec{\alpha} + \alpha_0 f = 0 \quad (1)$$

где $\vec{\alpha} = (\alpha_1, \alpha_2, \alpha_3)$, $\alpha_k \in C$, $k = 0, 1, 2, 3$; $f = (f_1, f_2, f_3)$, f_0 - векторная и скалярная функции соответственно в трехмерное евклидово пространство,

На кватернионнозначных функциях вида $F(x) = \sum_{k=0}^3 f_k(x) i_k$, $x \in \Omega \subset R^3$, $f_k(x) \in C^1(\Omega)$, $k = 0, 1, 2, 3$ определим оператор $D_\alpha F := (D + M^\alpha)F$, где $D := \sum_{k=1}^3 i_k \frac{\partial}{\partial x_k}$ - оператор, обобщающий двумерный оператор Коши-Римана (см. например [2]); $M^\alpha F := F\alpha$. Тогда уравнение $D_\alpha F = 0$ является эквивалентной записью системы (1).

Задача Коши. Требуется определить регулярное решение $F(y)$ системы (1) в области Ω , исходя из ее данных Коши, заданных на поверхности S :

$$F(y)|_S = g(y), \quad y \in S, \quad (2)$$

где $g(y) = \sum_{k=0}^3 g_k(y) i_k$ - заданная непрерывная кватернионно-значная функция.

Когда $\alpha \in C$, т.е. $\alpha \equiv \alpha_0$, фундаментальное решение G_α оператора D_α найдено по формуле (ср. [2] с. 76)

$$G_\alpha(x) = -[D_{-\alpha} h_\alpha](x) = h_\alpha(\alpha - x|x|^{-2} + i\alpha x|x|^{-1}), \quad (3)$$

где $h_\alpha(x) := -(4\pi|x|)^{-1} e^{-i\alpha|x|}$ - фундаментальное решение оператора Гельмгольца $\Delta + \alpha^2 I$ (см. например, [3]).

Обозначим $P^+ F := (2\gamma)^{-1} F(\gamma + \hat{\alpha})$, $P^- F := (2\gamma)^{-1} F(\gamma - \hat{\alpha})$.

Тогда справедливо следующее непосредственно проверяемое равенство:

$$D_\alpha F = D_\xi P^+ F + D_\varsigma P^- F$$

где $\xi = \alpha_0 + \gamma$, $\varsigma = \alpha_0 - \gamma$, $\gamma \in C$, $\gamma^2 = \hat{\alpha}^2$.

Заметим, что операторы P^+ и P^- являются взаимно дополнительными проекторами, коммутирующими с операторами D_ξ и D_ς .

Определение 1. Функция

$$G_\alpha := \begin{cases} P^+ G_\xi + P^- G_\varsigma; & \alpha \notin \Re \text{ и } \hat{\alpha}^2 \neq 0, \\ G_{\alpha_0} + \frac{\partial}{\partial \alpha_0} [G_{\alpha_0}] \hat{\alpha}, & \alpha \notin \Re \text{ и } \hat{\alpha} = 0, \\ P^+ G_{2\alpha_0} + P^- G_0, & \alpha \in \Re \text{ и } \alpha_0 \neq 0, \\ G_{\alpha_0} + h_0 \alpha, & \alpha \in \Re \text{ и } \alpha_0 = 0. \end{cases}$$

является фундаментальным решением оператора D_α .

Рассмотрим

$$K_\alpha := P^+ K_\xi + P^- K_\varsigma = -\frac{(\gamma + \hat{\alpha})}{2\gamma} [D_{-\xi} \Phi_\xi](x) - \frac{(\gamma - \hat{\alpha})}{2\gamma} [D_{-\varsigma} \Phi_\varsigma](x)$$

$$\Phi_\xi(x) = -\frac{1}{2\pi^2} \int_0^\infty \text{Im} \left[\frac{K(i\sqrt{u^2 + s} + y_3)}{i\sqrt{u^2 + s} + y_3 - x_3} \right] \frac{ch(\gamma + \hat{\alpha})u}{\sqrt{u^2 + s}} du,$$

$$D_{-\xi} \Phi_\xi(x) = (D\Phi_\xi + \Phi_\xi \cdot \xi) = \sum_{k=1}^3 i_k \frac{\partial \Phi_\xi}{\partial x_k} + \Phi_\xi \cdot \xi,$$

При $f \in \ker D_\alpha \cap C(\overline{\Omega})$, $\alpha \in Q$ справедливо интегральная формула Коши

$$F(x) = (K_\alpha F)(x), \quad x \in \Omega.$$

Определение 2. Функцией Карлемана задачи (1), (2) называется функция M_α^σ , удовлетворяющая следующим двум условиям:

$$1) K_\alpha^\sigma(x, y) = G_\alpha(x, y) + N_\alpha^\sigma(x, y),$$

где σ – положительный числовой параметр, функция $N_\alpha^\sigma(x, y)$ по переменной y удовлетворяет системе (1) всюду в области Ω , $G_\alpha(x, y)$ – фундаментальных решений оператора D_α ;

$$2) \int_T |K_\alpha^\sigma| dS_y \leq \varepsilon(\sigma) \text{ при фиксированном } x \in \Omega, \text{ где } \varepsilon(\sigma) \rightarrow 0 \text{ при } \sigma \rightarrow \infty; \text{ здесь и далее } |K_\alpha^\sigma|$$

означает евклидову норму, где

$$K_\alpha F = \begin{cases} P^+ K_\xi F + P^- K_\varsigma F, & \alpha \notin \Re \text{ и } \hat{\alpha}^2 \neq 0, \\ K_{\alpha_0} F + \frac{\partial}{\partial \alpha_0} [K_{\alpha_0} F], & \alpha \notin \Re \text{ и } \hat{\alpha}^2 = 0, \\ P^+ K_{2\alpha} F + P^- K_0 F, & \alpha \in \Re \text{ и } \alpha_0 \neq 0, \\ K_0 F - V_0 F \alpha, & \alpha \in \Re \text{ и } \alpha_0 = 0. \end{cases}$$

$$(K_\alpha F)(x) := - \int_{\partial\Omega} K_\alpha(x-y)n(y)F(y)dS_y, \quad x \in R^3 \setminus \partial\Omega,$$

$$(V_\mu F)(x) := \int_{\partial\Omega} h_\mu(x-y)n(y)F(y)dS_y, \quad \mu \in C, \quad x \in R^3,$$

$n(y)$ - внешняя нормаль к $\partial\Omega$ в точке y .

Положим

$$F_{\sigma\delta}(x) = (\mathfrak{I}_\alpha^{\sigma\delta} F)(x) =: - \int_S K_\alpha^\sigma(x-y)n(y)g_\delta(y)dS_y, \quad x \in \Omega.$$

Верна следующая

Теорема. Пусть $F \in \ker D_\alpha \cap C(\overline{\Omega})$, $\alpha \in Q$. На части T границы $\partial\Omega$ удовлетворяет условию

$$|F(y)| \leq B,$$

где B – заданное положительное число. Тогда для любого $x \in \Omega$ и $\sigma > 0$ справедливо формула Карлемана

$$\lim_{\delta \rightarrow 0} F_{\sigma\delta}(x) = F(x)$$

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ЗАДАЧА КОШИ ДЛЯ ВЕКТОРНОГО УРАВНЕНИЯ ГЕЛЬМГОЛЬЦА В ТРЕХМЕРНОЙ ОГРАНИЧЕННОЙ ОБЛАСТИ

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Хорошо известно, что задача Коши для эллиптического уравнения была широко исследована во многих практических областях. Например, некоторые задачи, относящиеся к геофизике [1], физике плазмы [2] и проблемам биоэлектрического поля [3], эквивалентны решению задачи Коши для эллиптического уравнения. Векторные уравнения Гельмгольца (ВУГ) является модельным уравнением эллиптического типа.

Задача Коши для векторного уравнения Гельмгольца часто встречается во многих областях, таких как акустика, электромагнетизм и упругость и т. д. Поэтому задача Коши для векторной уравнение Гельмгольца (ЗКВУГ) играет важную роль во многих инженерных приложениях и исследуется в таких областях физики многими авторами. Например, можно перечислить некоторые исследования, которые связаны с вибрацией конструкции, акустикой, электромагнитным рассеянием, распространением и рассеянием волн и т. д. С другой стороны, другая версия векторного уравнения Гельмгольца, которая называется модифицированным уравнением Гельмгольца (МУГ), рассматривается некоторыми авторами. Задача Коши для ВУГ или МВУГ некорректна в том смысле, что решение, если оно существует, не зависит непрерывно от заданных данных. Это означает, что небольшое возмущение заданных данных может вызвать большую ошибку в решении задачи. Следовательно, для получения устойчивого решения ВУГ необходима регуляризация.

В работе рассматривается задача продолжения решения ВУГ в ограниченной трехмерной области по ее значениям на части границы этой области, т.е. задача Коши. В линеаризованной теории потенциал скоростей Ψ удовлетворяет диссипативному волновому уравнению [4; с. 77-78.]

$$\frac{\partial^2 \Psi}{\partial t^2} + \gamma \frac{\partial \Psi}{\partial t} - c^2 \Delta \Psi = -F(x, t),$$

и, следовательно, для гармонически зависящих от времени акустических волн вида $\Psi(x, t) = U(x)e^{-i\omega t}$ с частотой $\omega > 0$ мы получим, волновому уравнению или уравнения Гельмгольца

$$\Delta U(x) + \lambda^2 U(x) \equiv \sum_{i=1}^3 \frac{\partial^2 U}{\partial x_i^2} + \lambda^2 U(x) = -f(x), \quad x \in \Omega, \quad (1)$$

где волновое число $\lambda \neq 0$, $\lambda^2 = \omega(\omega + i\gamma) / c^2$. Мы выберем знак λ так, что выполнялось условие $\text{Im} \lambda \geq 0$.

Пусть Ω ограниченная односвязная область в трехмерном пространстве R^3 с границей $\partial\Omega$, состоящей из компактной связной части T плоскости $y_3 = 0$ и гладкого куска поверхности S Ляпунова, лежащей в полупространстве $y_3 \geq 0$, $\bar{\Omega} = \Omega \cup \partial\Omega$, $\partial\Omega = S \cup T$. Обозначим через $H(\Omega)$ - множество функций удовлетворяющих векторное уравнение Гельмгольца в области Ω и принадлежащих классу $C^1(\bar{\Omega}) \cup C^2(\Omega)$.

Задача 1. (Задача Коши). Известны данные Коши решения ВУГ (1) на поверхности S :

$$[n, U(y)]|_S = f_1(y), \quad \text{div} U(y)|_S = f_2(y), \quad y \in S, \quad (2)$$

где $f_1(y), f_2(y)$ заданные на S функции классов $C^{1,\alpha}(S)$ и $C^{0,\alpha}(S)$ соответственно. Требуется восстановить функции $U(x)$ в Ω , исходя из заданной $f_1(y), f_2(y)$, т. е. решить задачу аналитического продолжения решения векторного уравнения Гельмгольца в пространственной области по ее значениям на гладком куске S границы.

Задача (1)–(2) для произвольных $\lambda(y)$, $f_1(y)$ и $f_2(y)$ неразрешима. Если S – аналитическая поверхность, $\lambda(y)$ аналитична на $\Omega \cup S$, функции $f_1(y)$ и $f_2(y)$ также аналитичны на S и аналитически продолжимы в Ω , то есть решение задачи 1 существует (тогда оно единственно ([5; с. 39.]]), однако оно неустойчиво.

Для ВУГ (1) в области Ω справедлива пространственная интегральная формула Кирхгорффа [6; с. 132]:

$$U(x) = \text{rot} \int_{\partial\Omega} [v(y), U(y)] \Phi_\sigma(y, x; \lambda) - \text{grad} \int_{\partial\Omega} (v(y), U(y)) \Phi_\sigma(y, x; \lambda) - \\ - \int_{\partial\Omega} \{ [\text{rot} U(y), v(y)] + v(y) \text{div} U(y) \} \Phi_\sigma(y, x; \lambda) dy, \quad (3)$$

где $\Phi_\sigma(y, x; \lambda)$ определяется формулой:

$$2\pi^2 e^{\sigma x_3^2 + \sigma \alpha^2 - \sigma y_3^2} \cdot \Phi_\sigma(y, x; \lambda) = \int_0^\infty \frac{\varphi_\sigma(y, x; u)}{u^2 + r^2} e^{-\sigma u^2} \text{ch}(\lambda u) du, \quad (4)$$

где

$$\varphi_\sigma(y, x; u) = \cos \tau \sqrt{u^2 + \alpha^2} - (y_3 - x_3) \frac{\sin \tau \sqrt{u^2 + \alpha^2}}{\sqrt{u^2 + \alpha^2}}, \quad \tau = 2\sigma y_3. \quad (5)$$

Предположим, что $U(y) \in H(\Omega)$ ограничена на части T границы $\partial\Omega$:

$$\left| \frac{\partial^i U(y)}{\partial y_j^i} \right| + \left| \frac{\partial}{\partial n} \frac{\partial^i U(y)}{\partial y_j^i} \right| \leq B, \quad y \in T, \quad (6)$$

где B – заданное положительное число.

Теорема. Пусть $U(x) \in H(\Omega)$ удовлетворяет условию (2) и на части T границы $\partial\Omega$ неравенства (6). Если f ограничена, локально непрерывная по Гёльдеру функция в Ω , то задача Коши (1)–(2) однозначно разрешима для любых $f_1(y)$ и $f_2(y)$ — заданных функций класса $C(S)$. Тогда для любого $x \in \Omega$ и $\sigma > 0$ справедливо неравенство

$$\left| \frac{\partial^i U(x)}{\partial x_j^i} - \frac{\partial^i U_\sigma(x)}{\partial x_j^i} \right| \leq C(\sigma) B \exp(-\sigma x_3^2), \quad (8)$$

где $i = 0, 1$ $j = 1, 2, 3$

$$C(\sigma) = \frac{2}{\sqrt{\pi}} \left(\frac{2}{\sqrt{\sigma}} + \frac{1}{\sigma \sqrt{\pi}} \right). \quad (9)$$

Следствие 1. Для любого $x \in \Omega$ справедливо равенство

$$\lim_{\sigma \rightarrow \infty} \frac{\partial^i U_\sigma(x)}{\partial x_j^i} = \frac{\partial^i U(x)}{\partial x_j^i} \quad (10)$$

причем предел достигается равномерно на компактах из Ω .

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IMPROVING THE METHODOLOGICAL SUPPORT FOR TEACHING THE COURSE "INFORMATION SECURITY" IN AN ELECTRONIC LEARNING ENVIRONMENT BASED ON DIGITALIZATION TECHNOLOGIES

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ABSTRACT

This paper presents a comprehensive study on enhancing the methodological support for teaching the "Information Security" course within an electronic learning environment (ELE) through the application of digitalization technologies. The rapid development of digital infrastructure in higher education has created both opportunities and challenges for delivering technically complex disciplines such as information security. The proposed approach integrates adaptive learning systems, cloud-based simulation platforms, interactive multimedia content, and automated assessment tools to create a robust pedagogical framework. The study examines the current shortcomings in conventional course delivery methods, analyzes international best practices, and proposes an improved model that aligns with modern digital competency standards. Experimental implementation at Gulistan State University demonstrated significant improvements in student engagement, knowledge retention, and practical skill acquisition. The findings confirm that digitalization-driven methodological support substantially increases the effectiveness of information security education.

Keywords: *information security, electronic learning environment, digitalization, methodological support, e-learning, adaptive systems, cybersecurity education.*

INTRODUCTION

The global transition to digital education has intensified the demand for modern, technology-enhanced teaching methodologies across all academic disciplines. Information security, as a discipline that lies at the intersection of theoretical knowledge and practical application, poses unique pedagogical challenges: the subject matter evolves rapidly, practical exercises require specialized environments, and the stakes of inadequate preparation are high given the growing cybersecurity threats facing institutions and individuals alike [1].

Electronic learning environments (ELEs) have become the primary medium for course delivery in many universities, yet methodological frameworks for disciplines such as information security have not kept pace with the technological capabilities now available. The introduction of digitalization technologies — including cloud computing, artificial intelligence, big data analytics, and virtual laboratories — opens new pathways for enriching instructional design, enabling interactive simulations, and personalizing the learning experience [2].

This paper investigates the gap between the existing methodological support provided for the "Information Security" course at higher education institutions in Uzbekistan and the standards that can be achieved through systematic integration of digitalization technologies. By developing and testing an improved methodological model, the study aims to contribute to the growing body of literature on technology-enhanced education while providing practical recommendations for educators and curriculum designers.

PROBLEM STATEMENT AND RESEARCH OBJECTIVES

The conventional delivery of information security courses in higher education institutions has revealed several critical deficiencies. First, the reliance on static lecture-based content fails to address the dynamic nature of cybersecurity threats and countermeasures. Second, the absence of

integrated practical environments means that students rarely gain hands-on experience with real tools and scenarios until they enter the workforce. Third, assessment methods remain largely summative and do not provide learners with timely, formative feedback necessary for mastery of technically demanding material [3].

The research objectives of this study are as follows: (1) to analyze existing methodological approaches used in teaching information security in Uzbekistan and internationally; (2) to identify specific gaps and deficiencies in the current electronic learning environment support; (3) to design an improved methodological framework integrating digitalization technologies; (4) to implement and evaluate the proposed framework through a controlled pedagogical experiment; and (5) to formulate evidence-based recommendations for educators and institutional decision-makers.

THEORETICAL FRAMEWORK AND METHODOLOGY

The theoretical basis of the proposed approach draws on constructivist learning theory, which posits that learners actively construct knowledge through experience and reflection [4]. In the context of information security education, this translates to creating learning environments where students can experiment, make mistakes, and refine their understanding in safe, controlled settings. This is complemented by the SAMR (Substitution, Augmentation, Modification, Redefinition) model of technology integration, which provides a structured lens for evaluating the degree to which digitalization transforms the learning experience [5].

The methodology of the study involved three phases. In the diagnostic phase, a survey of 180 students and 24 faculty members from three universities was conducted to assess current teaching practices and learner satisfaction. In the design phase, an improved methodological model was constructed incorporating the following elements: a cloud-based virtual laboratory (using open-source platforms such as GNS3 and VirtualBox); an adaptive learning module integrated into the Moodle LMS; video-lecture content aligned with internationally recognized cybersecurity frameworks (NIST, ISO/IEC 27001); and automated, scenario-based assessment tasks. In the experimental phase, the model was implemented with a cohort of 90 students over a single academic semester, with a parallel control group of 88 students receiving conventional instruction [6].

RESULTS AND DISCUSSION

Comparative analysis of pre- and post-test results demonstrated that students in the experimental group achieved statistically significantly higher scores in both theoretical knowledge assessments (mean increase of 22.4% vs. 11.7% in the control group) and practical skills evaluations (mean increase of 31.6% vs. 14.2% in the control group). Student satisfaction ratings, measured using the adapted System Usability Scale and a custom pedagogical satisfaction questionnaire, were also markedly higher in the experimental group (4.3/5.0 vs. 3.1/5.0) [7].

Qualitative feedback highlighted that students particularly valued the virtual laboratory environments, which allowed them to practice attack-and-defense scenarios without risk to real systems. Faculty participants reported that automated assessment tools reduced grading workload by an estimated 40%, allowing more time for mentorship and individualized feedback. Challenges identified during implementation included the need for initial technical training for instructors, occasional infrastructure limitations, and the importance of maintaining content currency given the fast-evolving nature of cybersecurity topics [8].

The findings align with international research demonstrating the effectiveness of blended and technology-enhanced approaches in STEM education. The specific application to information security in the context of Central Asian higher education contributes novel insights, particularly regarding the adaptability of established Western frameworks to local institutional settings and resource constraints.

CONCLUSIONS

This study demonstrates that the systematic integration of digitalization technologies into the methodological support for the "Information Security" course yields significant improvements in both learning outcomes and instructional efficiency. The proposed model — combining cloud-based virtual laboratories, adaptive LMS modules, multimedia content aligned with international

standards, and scenario-based automated assessment — offers a replicable framework for institutions seeking to modernize their information security curricula.

Future research should focus on longitudinal assessment of the model's impact on graduate readiness and professional performance, as well as on the integration of emerging technologies such as artificial intelligence-driven threat simulation and gamification elements into the electronic learning environment. Broader adoption of this approach across higher education institutions in Uzbekistan and the wider region has the potential to substantially elevate the quality of information security education and, by extension, national cybersecurity capacity.

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MOBIL ILOVALAR YARATISHDA ZAMONAVIY RAQAMLI TEXNOLOGIYALAR: TENDENSIYALAR VA ISTIQBOLLAR

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Annotatsiya: Ushbu tezisda zamonaviy mobil dasturlashning transformatsiyasi, xususan, platformalararo yechimlar, sun'iy intellekt integratsiyasi va kiberxavfsizlik masalalari tahlil qilinadi. Shuningdek, ilovalarning arxitekturaviy tuzilishi va foydalanuvchi tajribasini yaxshilashda raqamli vositalarning o'rnini ko'rsatib o'tilgan.

Asosiy qism

1. Platformalararo rivojlanish tendensiyalari. Hozirgi vaqtda mobil dasturlashda “Write Once, Run Everywhere” (Bir marta yoz, hamma yerda ishlat) tamoyili ustuvorlik qilmoqda. Bu yo'nalishda ikki yirik texnologiya yetakchilik qilmoqda:

- **Flutter (Dart):** Yuqori unumdorlik va vizual boy interfeyslarni ta'minlaydi.

- **React Native:** Veb-texnologiyalar va mobil platformalar o'rtasidagi integratsiyani amalga oshiradi.

2. Intellektual tizimlar va bulutli texnologiyalar. 2026-yilga kelib mobil ekotizim sun'iy intellekt va bulutli serverlar bilan uzviy bog'landi. Ilovalarning samaradorligini oshirishda quyidagilar hal qiluvchi ahamiyatga ega:

- **AI va ML:** NLP (tabiiy tilni qayta ishlash), Computer Vision va prediktiv tahlil orqali foydalanuvchiga moslashuvchan interfeyslar yaratilmoqda.

- **Cloud Native va Serverless:** Hisob-kitoblarni qurilmadan bulutli serverlarga (AWS, Google Cloud) ko'chirish orqali ilova hajmi kamaytirilmoqda va tezlik oshirilmoqda.

3. Foydalanuvchi ishonchi va xavfsizlik. Kengaytirilgan borliq (AR) texnologiyalari, masalan, virtual mebel joylashtirish funksiyasi, foydalanuvchi ishonchini 30-40% gacha oshirishi aniqlangan. Shu bilan birga, kiberhujumlarga qarshi biometrik autentifikatsiya, **End-to-end encryption** va **Blockchain** texnologiyalarini qo'llash zamon talabiga aylandi.

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FUQARO MUROJAATLARI GEOXARITASINI SHAKLLANTIRISH ALGORITMINI ISHLAB CHIQISH VA UNI RAQAMLI BOSHQARUV TIZIMLARIGA INTEGRATSIYALASH USULLARI

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Annotatsiya: Mazkur tezisda fuqarolar murojaatlarini geoxarita asosida vizual tahlil qilish algoritmini ishlab chiqish bosqichlari, uning texnologik asoslari hamda davlat boshqaruvi axborot tizimlariga integratsiyalash mexanizmlari keng yoritilgan. Taklif etilayotgan algoritm murojaatlarni hududiy monitoring qilish, muammoli zonalarini aniqlash hamda boshqaruv qarorlarini optimallashtirish imkonini beradi.

Kalit so'zlar: algoritm, GIS, geokodlash, spatial tahlil, interaktiv xarita, raqamli transformatsiya, monitoring tizimi.

Kirish.

Raqamli boshqaruv tizimlarining rivojlanishi fuqarolar murojaatlarini avtomatlashtirilgan tarzda qayta ishlashni talab etmoqda. Zamonaviy axborot texnologiyalaridan foydalanish orqali murojaatlarni hududiy kesimda tahlil qilish va vizual ko'rinishda taqdim etish davlat boshqaruvi samaradorligini oshirishda muhim vosita hisoblanadi.

Fuqaro murojaatlari geoxaritasini shakllantirish algoritmini ishlab chiqish orqali murojaatlar monitoringi tizimini yangi bosqichga olib chiqish mumkin.

Algoritmni ishlab chiqish bosqichlari Taklif etilayotgan algoritm quyidagi asosiy bosqichlardan iborat:

1-bosqich. Ma'lumotlarni yig'ish Mazkur bosqichda murojaatlar quyidagi manbalardan yig'iladi:

- davlat xizmatlari portallari;
- hududiy boshqaruv axborot tizimlari;
- mobil ilovalar;
- call-markazlar;
- elektron qabulxonalar.

Mazkur bosqichda ma'lumotlar CSV, JSON yoki ma'lumotlar bazasi formatida shakllantiriladi.

2-bosqich. Geokodlash jarayoni Geokodlash jarayoni algoritmining asosiy komponentlaridan biri hisoblanadi. Ushbu jarayonda manzil ma'lumotlari latitude va longitude koordinatalariga aylantiriladi.

Geokodlash quyidagi usullar orqali amalga oshiriladi:

- OpenStreetMap xizmatlari;

- Google Geocoding API;
- milliy geoaxborot platformalari.

Geokodlash aniqligi ko'rsatkichi (algoritm samaradorligini baholash)

Geokodlash jarayoni sifatini baholash uchun quyidagi formula qo'llaniladi:

$$A = (N_{\text{aniq}} / N_{\text{umumiy}}) * 100\%$$

Bu yerda:

A — geokodlash aniqligi (%);

N_{aniq} — to'g'ri koordinatalarga aylantirilgan manzillar soni;

N_{umumiy} — jami manzillar soni.

Bu ko'rsatkich algoritmning texnologik samaradorligini baholaydi.

Bu ko'rsatkich algoritmning texnologik samaradorligini baholaydi.

Mazkur jarayon xaritada aniqlik darajasini oshirishga xizmat qiladi.

3-bosqich. Ma'lumotlarni filtrlash va kategoriyalash Mazkur bosqichda murojaatlar quyidagi mezonlar asosida guruhlanadi:

- murojaat mavzusi;
- murojaat hududi;
- murojaat sanasi;
- murojaat statusi.

Filtrlash algoritmлари yordamida ortiqcha ma'lumotlar chiqarib tashlanadi.

4-bosqich. GIS tizimiga integratsiya Mazkur bosqichda tayyorlangan ma'lumotlar GIS platformalariga yuklanadi:

- QGIS;
- ArcGIS;
- Leaflet;
- Mapbox.

Mazkur platformalar spatial tahlil imkoniyatlarini kengaytiradi.

5-bosqich. Vizualizatsiya va interaktiv interfeys yaratish Mazkur bosqichda quyidagi texnologiyalar qo'llaniladi:

- markerlar;
- klasterlash;
- heatmap;
- vaqt bo'yicha filtrlar;
- tematik qatlamlar.

Natijada foydalanuvchi uchun qulay interaktiv boshqaruv paneli shakllantiriladi.

6-bosqich. Analitik modulni joriy etish Algoritm tarkibiga analitik modul qo'shilishi orqali quyidagi imkoniyatlar yaratiladi:

- murojaatlar sonini avtomatik hisoblash;
- hududlar kesimida solishtirma tahlil;
- vaqt bo'yicha dinamikani aniqlash;
- prognozlash modelini shakllantirish.

Mazkur modul Python dasturlash tilidagi Pandas, GeoPandas va Folium kutubxonalari asosida amalga oshirilishi mumkin.

Algoritmning afzalliklari taklif etilayotgan algoritm quyidagi ustunliklarga ega:

- avtomatlashtirilgan monitoring;
- real vaqt rejimida kuzatuv;
- muammoli hududlarni tezkor aniqlash;
- statistik tahlilni soddalashtirish;
- boshqaruv qarorlarini optimallashtirish.

Amaliy qo'llanish sohalari. Mazkur algoritm quyidagi yo'nalishlarda samarali qo'llanishi mumkin:

- kommunal xizmatlar monitoringi;
- transport infratuzilmasini tahlil qilish;
- ijtimoiy soha monitoringi;

- ekologik muammolarni aniqlash;
- hududiy rivojlanish strategiyalarini ishlab chiqish.

Xulosa qilib aytganda, fuqaro murojaatlari geoxaritasini shakllantirish algoritmini ishlab chiqish raqamli boshqaruv tizimlarini takomillashtirishda muhim ahamiyat kasb etadi. Ushbu algoritm asosida yaratilgan interaktiv xaritalar orqali hududiy muammolar aniqlanadi hamda davlat organlari faoliyatining samaradorligi oshadi.

Kelgusida mazkur algoritmnini sun'iy intellekt texnologiyalari, katta hajmdagi ma'lumotlarni qayta ishlash platformalari hamda prognozlash modullari bilan integratsiya qilish orqali uning funksional imkoniyatlarini yanada kengaytirish mumkin.

Foydalanilgan adabiyotlar

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FUQARO MUROJAATLARINI GEOXARITALASH ASOSIDA HUDUDY MUAMMOLARNI ANIQLASH VA BOSHQARUV SAMARADORLIGINI OSHIRISH

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Annotatsiya: Mazkur tezisda fuqarolarning davlat organlariga yo'llayotgan murojaatlarini geografik axborot tizimlari (GIS) asosida tahlil qilishning nazariy va amaliy jihatlari yoritilgan.

Shuningdek, murojaatlar geoxaritasini shakllantirish orqali hududiy muammolarni aniqlash, boshqaruv qarorlarini tezkor qabul qilish hamda elektron hukumat tizimi samaradorligini oshirish masalalari ko'rib chiqiladi.

Kalit so'zlar: elektron hukumat, fuqarolar murojaati, geoxarita, GIS texnologiyalar, raqamli boshqaruv, hududiy tahlil.

Kirish.

So'nggi yillarda O'zbekiston Respublikasida davlat boshqaruvi tizimini raqamlashtirish, aholiga ko'rsatilayotgan davlat xizmatlari sifatini oshirish hamda fuqarolar bilan samarali muloqotni yo'lga qo'yish borasida keng ko'lamli islohotlar amalga oshirilmoqda. Ayniqsa, elektron hukumat tizimining rivojlanishi natijasida fuqarolarning davlat organlariga murojaat qilish imkoniyatlari sezilarli darajada kengaydi.

Bugungi kunda fuqarolar murojaatlari sonining ortib borishi ularni tahlil qilishning zamonaviy usullarini qo'llashni talab etmoqda. Shunday usullardan biri murojaatlarni geografik jihatdan vizual tahlil qilish hisoblanadi. Geoxaritalash orqali murojaatlarning hududiy taqsimoti aniqlanadi hamda muammoli hududlarni tezkor aniqlash imkoniyati yaratiladi.

Asosiy qism Fuqaro murojaatlarini geoxaritalash jarayoni bir nechta muhim bosqichlardan iborat bo'lib, ular quyidagilarni o'z ichiga oladi:

Birinchi bosqich — ma'lumotlarni yig'ish. Ushbu bosqichda murojaatlar quyidagi manbalardan olinadi:

- Yagona interaktiv davlat xizmatlari portali;
- hududiy hokimliklar murojaatlar bazasi;
- call-markazlar; — mobil ilovalar.

Har bir murojaat tarkibida hududiy tahlil uchun zarur bo'lgan quyidagi atributlar mavjud bo'lishi lozim:

- murojaat identifikatsiya raqami;
- murojaatchining yashash hududi;
- murojaat mavzusi;
- murojaat sanasi;
- murojaat holati;
- geografik koordinatalar.

Mazkur bosqichda murojaatlar hududlar kesimida, mavzular bo'yicha, vaqt oralig'i hamda murojaat statusiga ko'ra guruhlanadi.

Hududiy murojaatlar zichligini aniqlash quyidagi formula asosida hisoblandi:

$$D = N / S \quad (1)$$

bu yerda:

D — murojaatlar zichligi

N — hududdagi murojaatlar soni

S — hudud maydoni

Mazkur ko'rsatkich orqali muammoli hududlar aniqlanadi hamda resurslarni samarali taqsimlash imkoniyati yaratiladi.

Muammolar ustuvorligini aniqlash uchun quyidagi indeksdan foydalanildi:

$$I = N_t / N_{umumiy} \quad (2)$$

bu yerda:

I — muammo ustuvorligi indeksi

N_t — muayyan turdagi murojaatlar soni

N_{umumiy} — jami murojaatlar soni

Mazkur indeks orqali qaysi sohada muammolar ko'proq uchrayotgani aniqlanadi.

Ikkinchi bosqich — ma'lumotlarni tozalash va standartlashtirish. Ushbu jarayonda noto'g'ri yoki takroriy yozuvlar aniqlanadi va bartaraf etiladi. Shuningdek, manzil ma'lumotlari geokodlash orqali koordinatalarga aylantiriladi.

Uchinchi bosqich — ma'lumotlarni tahlil qilish.

Bu bosqichda murojaatlar quyidagi mezonlar asosida guruhlanadi:

- hududlar kesimida;
- murojaat mavzulari bo'yicha;
- vaqt oralig'i bo'yicha;
- murojaat statusi bo'yicha.

Mazkur tahlil hududlarda mavjud muammolarni aniqlash hamda ularning takrorlanish darajasini baholash imkonini beradi.

To'rtinchi bosqich — geoxarita yaratish. Ushbu bosqichda GIS texnologiyalari yordamida murojaatlar xaritada vizual aks ettiriladi. Rangli markerlar orqali murojaat turlari ajratiladi hamda interaktiv filtrlar orqali foydalanuvchilarga qulay interfeys yaratiladi.

Geoxaritalashning afzalliklari Fuqaro murojaatlarini geoxaritalash quyidagi afzalliklarni ta'minlaydi:

- hududiy muammolarni tezkor aniqlash;
- murojaatlar dinamikasini kuzatish;
- boshqaruv qarorlarini asosli qabul qilish;
- resurslarni samarali taqsimlash;
- davlat organlari faoliyati ochiqligini ta'minlash.

Bugungi kunda GIS texnologiyalaridan foydalanish orqali murojaatlar monitoringini avtomatlashtirish imkoniyati mavjud. Bu esa inson omili ta'sirini kamaytiradi hamda tahlil aniqligini oshiradi.

Natijalar va muhokama Geoxaritalash asosida amalga oshirilgan tahlillar natijasida hududlarda eng ko'p uchraydigan muammolar aniqlanadi. Masalan, ayrim hududlarda kommunal xizmatlar, transport infratuzilmasi yoki ijtimoiy xizmatlar bilan bog'liq murojaatlar ko'proq uchrashi mumkin. Mazkur ma'lumotlar asosida davlat organlari tomonidan muammolarni bartaraf etish bo'yicha manzilli chora-tadbirlar ishlab chiqiladi.

Xulosa qilib aytganda, Fuqaro murojaatlarini geoxaritalash davlat boshqaruvi tizimining samaradorligini oshirishda muhim ahamiyat kasb etadi. Ushbu texnologiya orqali hududiy muammolar aniqlanadi, boshqaruv qarorlari tezkor qabul qilinadi hamda fuqarolar bilan samarali muloqot tizimi shakllanadi.

Kelgusida mazkur tizimni sun'iy intellekt texnologiyalari bilan integratsiya qilish orqali murojaatlarni prognozlash hamda avtomatik tahlil qilish imkoniyatlarini kengaytirish maqsadga muvofiq hisoblanadi.

Foydalanilgan adabiyotlar

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CREATING 4D GAUSSIAN SPLATTING CONTENT FOR DYNAMIC SCENE RECONSTRUCTION FROM SPARSE CAMERAS

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Abstract. Recent advances in neural rendering have enabled efficient reconstruction of dynamic scenes. Among these approaches, 4D Gaussian Splatting (4DGS) has emerged as a promising representation for modeling dynamic environments with high rendering quality and real-time performance. This paper investigates the process of creating 4DGS content from multi-view video sequences captured by sparse camera setups. We analyze the pipeline for generating dynamic scene representations using Gaussian primitives and discuss optimization strategies for improving geometric consistency and temporal stability. Experimental observations demonstrate that 4DGS enables high-quality dynamic scene reconstruction while maintaining real-time rendering performance. The proposed framework contributes to the development of immersive media applications such as virtual reality, volumetric video, and holographic displays. The implementation of 4DGS offers transformative potential for immersive media, including volumetric video production, telepresence systems, and digital twins. Furthermore, integrating this representation with holographic display technologies provides a robust foundation for next-generation visualization and augmented reality applications.

Keywords: 4D Gaussian Splatting, Dynamic Scene Reconstruction, Neural Rendering, Volumetric Video, Computer Vision

1. Introduction

Dynamic scene reconstruction is a fundamental problem in computer vision and computer graphics. The ability to reconstruct scenes in both spatial and temporal dimensions enables applications in immersive media, virtual reality, telepresence, and digital content production. Traditional multi-view capture systems rely on large camera arrays to capture dynamic scenes with high fidelity. However, such systems are expensive and difficult to deploy.

Recent developments in neural rendering, particularly neural radiance fields and Gaussian-based representations, have significantly improved the efficiency of scene reconstruction. The introduction of **3D Gaussian Splatting** enabled real-time rendering of static scenes by representing the environment using a set of anisotropic Gaussian primitives. Extending this concept, **4D Gaussian Splatting (4DGS)** incorporates temporal information, enabling the modeling of dynamic scenes.

In this paper, we focus on the problem of **creating 4DGS content** using sparse camera setups. Our goal is to analyze the pipeline required for generating high-quality dynamic scene representations using Gaussian primitives. The main contributions of this work are as follows:

1. Analysis of the 4DGS pipeline for dynamic scene reconstruction.
2. Discussion of techniques for generating 4DGS content from sparse camera data.
3. Evaluation of the potential applications of 4DGS in immersive media systems.

2. Related Work

Recent research in neural scene representation has produced several methods for novel view synthesis and dynamic scene modeling. Neural Radiance Fields (NeRF) represent scenes as continuous volumetric functions learned by neural networks. While NeRF-based methods achieve high-quality rendering, they often suffer from slow training and rendering times.

Gaussian-based representations have recently gained attention due to their efficiency. The introduction of **3D Gaussian Splatting** demonstrated that explicit Gaussian primitives could be used for real-time scene rendering. These primitives encode spatial location, covariance, opacity, and color information, enabling efficient rasterization.

Dynamic scene modeling has also been explored through various extensions of NeRF and Gaussian representations. Approaches such as deformation-based Gaussian models and spatio-temporal radiance fields attempt to capture object motion over time. Among these methods, **4D Gaussian Splatting** represents scenes as time-dependent Gaussian primitives, allowing dynamic scene reconstruction with improved rendering speed.

3. Methodology

3.1 4D Gaussian Representation

In 4D Gaussian Splatting, a dynamic scene is represented as a collection of Gaussian primitives. Each primitive is defined by a set of parameters:

- Spatial position
- Scale and orientation
- Opacity
- Color coefficients
- Temporal attributes

These parameters allow the Gaussian primitives to evolve over time, enabling the modeling of dynamic scenes.

3.2 4DGS Content Creation Pipeline

The pipeline for generating 4DGS content consists of the following steps:

1. Multi-View Data Acquisition

Dynamic scenes are captured using multiple synchronized cameras.

2. Camera Calibration

Camera intrinsics and extrinsics are estimated using structure-from-motion algorithms.

3. Initialization of Gaussian Primitives

Sparse point clouds are generated from multi-view reconstruction and converted into Gaussian primitives.

4.Optimization

The Gaussian parameters are optimized using photometric reconstruction loss.

5.Dynamic Rendering

The optimized Gaussian representation is used to render novel viewpoints at different time steps.

4. Experimental Discussion

The proposed pipeline demonstrates that dynamic scenes can be reconstructed effectively using Gaussian-based representations. Compared with volumetric neural rendering approaches, 4DGS provides several advantages:

- Faster training and rendering
- Explicit scene representation
- Real-time performance

These properties make 4DGS particularly suitable for interactive applications such as virtual reality and immersive broadcasting.

5. Conclusion

This paper presented an overview of creating 4D Gaussian Splatting content for dynamic scene reconstruction. We analyzed the pipeline for generating dynamic scene representations from multi-view videos and discussed the advantages of Gaussian-based approaches. The results indicate that 4DGS is a promising technique for efficient dynamic scene modeling and real-time rendering. Future work will focus on improving reconstruction quality in sparse camera setups and exploring integration with holographic display technologies.

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BO‘LAJAK MUHANDIS-DASTURCHILARNI TAYYORLASHDA INNOVATSION TA’LIM SHAKLLARI VA DASTURLASH TILLARINING PEDAGOGIK IMKONIYATLARI

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Annotatsiya. Mazkur maqolada bo‘ljak muhandis-dasturchilarning kasbiy kompetensiyalarini rivojlantirishda dasturlash tillarining pedagogik imkoniyatlari tahlil qilingan. Tadqiqotda innovatsion ta‘lim shakllari — ekskursion-dars, kombinatsion-dars va konferension-dars asosida talabalarning algoritmlash, modellashtirish, loyihalash hamda avtomatlashtirish kompetensiyalarini shakllantirish mexanizmlari yoritilgan. Shuningdek, differensial, evristik, loyihalash va tanqidiy fikrlash texnologiyalarining ta‘lim samaradorligini oshirishdagi ahamiyati asoslab berilgan.

Bo‘ljak muhandis-dasturchilarning kasbiy kompetensiyalarini shakllantirish jarayonida dasturlash tillarining ta‘sirini va imkoniyatlarini aniqlash zarur. Bu jarayonda ta‘lim muassasalarida dasturlash tillaridan foydalanishga nisbatan bir qator qarama-qarshi fikrlar mavjud:

- Yangi bilimlarni mustaqil ravishda egallashda dasturlash tillaridan samarali foydalanish uchun yetarli malakalarning yetishmasligi, bu esa o‘quvchilarning o‘zlashtirish darajasini pasaytirishi mumkin.

Oliy ta‘lim muassasalarida talabalar uchun kasbiy kompetensiyalarni shakllantirish zarurati mavjud bo‘lsa-da, dasturlash tillarini o‘rganish uchun pedagogik shart-sharoitlarning yetarli emasligi, bu esa talabalarning ta‘lim jarayonida to‘liq foyda olishlariga to‘sqinlik qilishi mumkin.

Shuning uchun, bu masalalar bo‘yicha aniqlik kiritish va tegishli yechimlarni topish, ta‘limning

sifatini oshirish va talabalarning kelajakdagi muvaffaqiyatini ta'minlash uchun muhimdir.

Talabalarning dasturlash tilidan foydalanib kasbiy kompetensiyalarni shakllantirish jarayonining pedagogik shart-sharoitlari quyidagilar: dasturlash tillaridan elektron ta'lim, mul'timedia, masofadan o'qitish va ilg'or texnologiyadan foydalanish; matematika fanini o'qitishda ijodiy vazifalarni tanlash orqali talabalarning bilimini oshirish va kasbiy tayyorgarligini rivojlantirishni ta'minlash; o'qitishning informasion va axboriy-didaktik ta'minotni rivojlantirish.

Ta'limda fanlararo aloqalarni ta'minlash bo'lajak muhandis-dasturchilarning kasbiy kompetensiyalarini shakllantirishning muhim sharti hisoblanadi. Bu jarayon ta'limda uzviylik va o'zaro aloqadorlikni ta'minlash bilan birga, matematik voqeliklarni yangi ta'lim usullari orqali ishlab chiqishni ham o'z ichiga oladi. Fanlararo aloqadorlikka erishishda amaliy mazmundagi masalalar katta ahamiyatga ega. Birinchidan, bu talabalarga funksiyalarni modellashtirishni amalga oshirishda yordam beradi. Ikkinchidan, amaliy mazmundagi masalalarni yechishda fundamental bilimlardan foydalanish orqali talabalarning boshqa fanlarni o'rganish jarayonida qo'llash ko'nikmalarini rivojlantirishga olib keladi.

Bo'lajak muhandis-dasturchilarni kasbiy tayyorgarligini rivojlantirishning tashkiliy-funksional modelini ishlab chiqdik.

Tashkiliy-funksional modelni ta'lim jarayonida qo'llanilishini keltirib o'tamiz.

Ekskursion-Darsda:

Bo'lajak muhandis-dasturchilarga ekskursion-Dars hamkor tashkilotlarga tashrif buyurish orqali amalga oshiriladi. Bunda talabalar ishlab chiqarishni bevosita kuzatish, yetakchi muhandis-dasturchilar bilan tanishish va fikr almashish imkoniyatiga ega bo'ladilar. Ekskursion-Darsda evristik va tanqidiy fikrlash texnologiyasidan foydalaniladi, bunda talabalarning algoritmlash va modellashtirish kompetensiyalari shakllantiriladi. Ekskursion-Dars odatda auditoriyadan tashqari mashg'ulot bo'lib, asosan texno-parklarda yoki IT-markazlarda o'tkazilishi mumkin.

Evristik pedagogik texnologiyalarni qo'llashda talabalarning kasbiy tayyorgarligi faollashadi, masalan: muvozanat, stressga chidamlilik, o'z-o'zini anglash motivatsiyasi, ijodkorlik, kreativlik. Ushbu ta'lim metodi ko'pincha yangi mavzuni tushuntirishda qo'llaniladi.

Evristik ta'lim texnologiyasi — bu ta'lim oluvchiga o'quv jarayonining o'ziga xos mazmuni, maqsadlari va tuzilishini, shuningdek, uni tashkil etish, diagnostika va tushunish jarayonlarini mustaqil ravishda tayyorlashni o'rgatishga qaratilgan ta'limdir, deb ta'riflaydi A.V. Xutorskiy [1].

Tanqidiy fikrlash texnologiyasi – kasbiy muammolarni muhokama qilish, baholash, aniqlash va hal qilishni o'rgatadigan ta'lim texnologiyasidir.



1-rasm. Ekskursion darsning sxematik ko'rinishi

Kombinatsion-Darsda:

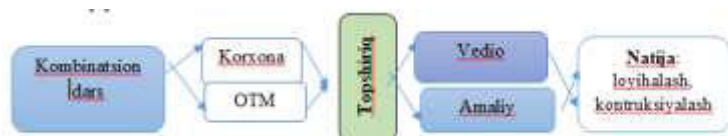
Kombinatsion darslarda loyihalash texnologiyasini qo'llash orqali talabalarning loyihalash va konstruksiyalash funksionallik kompetensiyalarini shakllantirish amalga oshiriladi.

Kombinatsion dars ma'ruza, amaliy, laboratoriya, to'garak kabi ta'lim shakllarining barchasini birdek loyihalash texnologiyasidan foydalanib olib borilishidir. Kombinatsion-dars hamkor tashkilotlar bilan uzviylikda fan dasturlarini ishlab chiqish, amaliyot jarayonlarini muvofiqlashtirish, hamkorlikda uslubiy ta'minotni rivojlantirishda samarali hisoblanadi. Bundan tashqari ishlab chiqarishning yetakchi xodimlarini ham ta'lim jarayoniga jalb qilish nazarda tutiladi.(2-rasm)

Zamonaviy metodika va texnologiyalarning turli yo'nalishlari orasida eng maqbul maqsadlarga erishtiruvchi metod-loyihalash metodi hisoblanadi. Loyihalash metodi — talabalarni bosqichma-bosqich murakkablashib boradigan amaliy masalalarni ishlab chiqish, rejalashtirish va amalga oshirish jarayonida bilim, ko'nikma va malakalar bilan ta'minlaydigan ta'lim tizimidir.

Loyihalash metodikalarining samaradorligi quyidagi sabablarga asoslanadi: loyihalash metodikasi shaxsga yo'naltirilgan bo'lib, bunda ta'limni rivojlanish jihati kasbiy ta'limda yetakchilik qiladi; loyihani amalga oshirish jarayonida ta'lim shaxsning o'zi tomonidan motivlashgan bo'lib, bu o'z navbatida ishni bajarish jarayonida unga bo'lgan qiziqish va ishga berilishni kuchaytiradi; loyihalash metodikasida "o'qituvchi-talaba" munosabatlari ierarxiyasi (po g'onalari, ketma-ketligi) an'anaviy ta'lim metodlaridan tubdan farq qiladi.

Loyihalash texnologiyasi - o'qituvchi rahbarligida, o'qituvchi va talabalarning o'zaro aloqasi asosidagi maqsadli, mustaqil faoliyati. O'qituvchi loyiha ustida ishlash jarayonida barcha talabalarning ijobiy emosional kayfiyatini uyg'otadi va teng huquqli ishonchga asoslangan sherikchilik muloqotini o'rnatadi. Ushbu texnologiyaning mohiyati — ma'lum bilimlar hajmini egallash va loyihalash faoliyati orqali olingan bilimlarni amalda qo'llash imkonini beradigan, talabalarning muayyan muammolarga qiziqishini rag'batlantirishdir. Bu loyiha talabalarning muayyan vaqt davomida individual, juftlik yoki guruh bo'lib ishlashiga mo'ljallangan. — M. S. Sultanova[2].



2-rasm. Kombinatsion darsning sxematik ko'rinishi

Konferension-Darsda:

Konferension-Darsda differensial ta'lim texnologiyasini qo'llash orqali talabalarning dasturlash va avtomatlashtirish kompetensiyalarini shakllantirish amalga oshiriladi. Konferension-dars internetda ijtimoiy tarmoqlar (telegram, instagram, facebook) differensial texnologiyasidan foydalanib olib borilishidir.(3-rasm)

Differentsiallashtirish o'quv jarayoni deganda talabalarning ma'lum o'quv fanlari bo'yicha o'quv materiallarini turli darajada («A», «B», «S») egallashlariga qaratilgan ta'lim-tarbiya jarayonini tashkil etish tushuniladi.



3-rasm. Konferension darsning sxematik ko'rinishi

Bo'lajak muhandis-dasturchilarning kasbiy tayyorgarligini rivojlantirish texnologiyalari ishlab chiqildi. Bo'lajak muhandis-dasturchilarni kasbiy tayyorgarligini rivojlantirishning tashkiliy-funksional modelini ishlab chiqildi. Innovatsion ta'lim shakllari: kombinatsion-Dars, ekskursion-dars, konferension-Darslarda ta'lim texnologiyalardan: differensial o'qitish texnologiyasi, loyihalash texnologiyasi, evristik ta'lim texnologiyasi, tanqidiy fikrlash texnologiyasidan samarali foydalanilib talabalarning kasbiy kompetensiyalari shakllantirildi, kasbiy tayyorgarligi takomillashtirildi.

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THE USE OF INFORMATION SYSTEMS FOR MANAGING CUSTOMER RELATIONSHIPS IN AN ENTERPRISE IN A DIGITAL ECONOMY

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Annotation. CRM systems are enterprise-wide information systems that are designed to collect and analyze customer data, perform multi-factor classification of objects, and build optimal models of interaction with partners and customers. The article discusses the main reasons for the appearance of CRM systems, their main functions and classification of tasks.

Keywords: Internet, interactive marketing, CRM system, ERP systems, client, information and communication technologies.

Introduction

Currently, dialogue with the consumer is one of the main conditions for the successful operation of the company in the market. In particular, interactive marketing is faced with the task of managing customer relationships based on the latest information and communication technologies.

One of the key problems solved in customer relationship management is the management that is associated with customer churn. The customer relationship management system (CRM) is an integral part of the marketing automation information system [1]. Nowadays, so-called ERP (Enterprise Resource Planning) - enterprise resource planning systems are used to automate and optimize the internal activities of companies. These systems are aimed at improving processes such as planning, execution of plans, control and accounting. Thus, ERP systems are used in order to achieve advantages over competitors by optimizing some business processes within the enterprise.

Literature Review

The opposite system is the so-called customer relationship management system (CRM), in which the company's customers are in the spotlight. These systems make it possible, so to speak, to integrate customers into the enterprise. The company always receives the most necessary information about its customers and their requirements[2]. Based on these data, the company builds a marketing program. Based on this, it follows that CRM systems are an important part of automated marketing information systems.

Materials and methods

Speaking about the use of data that the CRM system can generate, it should be noted that this information can be used not only by the company's employees, but also by the customers themselves. CRM systems allow customers who have applied to the company for the first time to choose the products they need in real time. The involvement of the client in the process of forming an order allows us to provide an individual approach to each consumer. This aspect is so important that the creation of CRM systems should be focused on both internal and consumer use.

Results

The algorithm for working with the customer base [6] includes the following key blocks (Fig. 1). Calculating the loyalty index for different time periods allows you to track trends in the share of regular and casual customers for different segments of the customer base. The loyalty index is calculated using the following formula:

$$I_{\text{л}} = \left(\frac{\Pi_{\text{кл}1}}{\Pi_{\text{кл}0}} \right) * \alpha_n + \left(\frac{P_{\text{кл}1}}{P_{\text{кл}0}} \right) * \alpha_p$$

Where: $I_{\text{л}}$ - loyalty index; $\Pi_{\text{кл}0}$, $\Pi_{\text{кл}1}$ - he number of regular (more than two purchases per year) customers in the first and zero periods; $P_{\text{кл}0}$, $P_{\text{кл}1}$ - the number of one-time (two or less purchases per year) customers in the first and zero period; α_n - is the constant clientele ratio (=1); α_p is the coefficient of random clientele (=0.3);

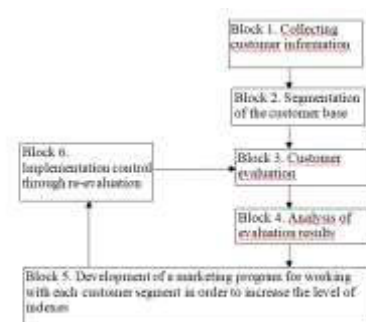


Figure 1. Flowchart of the algorithm for working with the client base.

Based on expert opinions, the coefficient values for regular and one-time customers were determined as 1 and 0.3, respectively, although the values may vary depending on specific details and therefore the index value is determined by the company individually.

We suggest using a value index to measure the value of each customer. Customer value means measurable characteristics that are useful to the company. Using the profit indicator in the numerator, it is possible to identify customer segments with high volumes of purchases, which on average will bring the company more profit than low-profit ones, which have a larger customer volume. The customer value index is calculated using the following formula:

$$I_u = \frac{C_{np}}{I_6} * K_{p3} * K_{yo}$$

Where: I_u – value index; K_{p3} - the coefficient of regularity of purchases (1 - at least once a quarter, 0.9 - once a half-year, 0.8 - once a year or less); K_{yo} - coefficient of payment terms (1.1 - prepayment, 1.0 - release of products on loan); C_{np} - the amount of profit for the period, soums; I_6 - the cost of one point of value, soums per unit of value.

Customer satisfaction ratings are most often carried out by managers, but it is preferable if an employee who does not work directly with the client is engaged in questioning the company's clients in order to reduce the degree of influence of personal interests of managers on the evaluation results. At the same time, we get a more objective assessment. To assess the level of customer satisfaction of an enterprise, a special index can be proposed for use. In order to assess the satisfaction of the company's customers, we propose to conduct a customer survey and use the weight (importance to the customer) of each proposed evaluation criterion and a special indicator to assess customer satisfaction. The satisfaction index is calculated using the following formula:

$$I_y = \sum_{i=1}^n O_i * B_i$$

Where: I_y – satisfaction index; i – number of evaluation criteria; n – total number of evaluation criteria; O_i – is the weight of the i -th criterion; B_i – evaluation of the criterion.

Discussions

We propose a set of organizational changes at the enterprise required for the successful implementation of the customer relationship management strategy in the enterprise management system, including five main areas: the adoption of a customer relationship management strategy, the introduction of an algorithm for working with the customer base and changing the business processes of the enterprise, making changes to the organizational structure of enterprises for the successful implementation of the algorithm with the customer base, corporate culture change, CRM system implementation.

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МЕТОДОЛОГИЧЕСКИЕ АСПЕКТЫ ЦИФРОВОЙ ТРАНСФОРМАЦИИ РАБОЧЕГО МЕСТА SMM-СПЕЦИАЛИСТА НА ОСНОВЕ АВТОНОМНЫХ ИИ-АГЕНТОВ

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Аннотация: В статье рассматривается процесс интеграции автономных ИИ-агентов в рабочую среду SMM-специалистов как ключевой элемент цифровой трансформации маркетинга. Анализируется переход от статических инструментов автоматизации к динамическим интеллектуальным системам на базе больших языковых моделей (LLM). Предложена концептуальная модель взаимодействия человека и ИИ (Искусственный интеллект), направленная на оптимизацию когнитивной нагрузки и повышение эффективности рекламных кампаний.

Ключевые слова: искусственный интеллект, ИИ-агенты, SMM, цифровая трансформация, автоматизация маркетинга, LLM, нейронные сети.

Современный этап развития цифровой экономики характеризуется массовым внедрением технологий искусственного интеллекта в сферу коммуникаций. В данных условиях процесс интеграции автономных ИИ-агентов в рабочую среду SMM-специалистов выступает как ключевой элемент цифровой трансформации маркетинга. Для SMM-специалистов (Social Media Marketing) это означает переход от использования ИИ как вспомогательного инструмента для генерации текста к внедрению автономных агентов, способных выполнять комплексные задачи с минимальным участием человека. Настоящая работа исследует переход от статических инструментов автоматизации к динамическим интеллектуальным системам на базе LLM.

От автоматизации к автономии: концептуальный сдвиг

Классические системы автоматизации, традиционно применяемые в сфере маркетинга в социальных сетях (SMM), функционируют на основе жестко заданных алгоритмов, преимущественно реализуемых в логике «если-то» (IF-THEN). Эти системы, хотя и обеспечивают определенный уровень эффективности для рутинных и предсказуемых задач, таких как запланированная публикация контента или простейшая модерация, обладают фундаментальными ограничениями. Их функционирование полностью зависит от заранее

определенных правил и условий, что делает их малопригодными для адаптации к динамично меняющейся среде социальных медиа. Отсутствие способности к контекстному пониманию, не говоря уже о генерации новых идей или автономному принятию решений, не позволяет им эффективно реагировать на непредсказуемые изменения в поведении аудитории, внезапные тренды или нюансы коммуникации, требующие более глубокого анализа и гибкой стратегии[1].

Принципиально иной подход демонстрирует внедрение автономных интеллектуальных агентов, разработанных на базе передовых архитектур больших языковых моделей, таких как GPT-4, или аналогичных им по сложности и возможностям. Эти модели, обладающие беспрецедентными способностями к обработке естественного языка, пониманию сложных контекстов и генерации связного, релевантного контента, открывают путь к реализации так называемых «агентских циклов» (agentic workflows). В отличие от простой автоматизации, основанной на детерминированных правилах, агентские циклы представляют собой итеративный процесс, где интеллектуальный агент не просто выполняет заданные инструкции, а проактивно действует, исходя из заданной цели, способен к обучению и самокоррекции. Это знаменует собой переход от реактивного исполнения к проактивному, целеориентированному поведению, что существенно расширяет горизонты применения ИИ в стратегическом SMM.

Автономный агент получает стратегическую цель, например, увеличение вовлеченности на 15%, и самостоятельно декомпозирует ее на измеримые подзадачи с определением метрик и путей их выполнения. На этапе планирования формируется контент-план, где выбор форматов, каналов и временных интервалов основывается на анализе данных. Непрерывный мониторинг реакции аудитории (вовлеченность, сентимент) позволяет агенту оперативно корректировать стратегию. Эта адаптация содержания и взаимодействия обеспечивает гибкость и оптимизацию достижения цели, что является ключевым преимуществом таких систем[2,3].

Архитектура интеграции ИИ-агента в SMM-процессы

С целью всестороннего понимания и эффективного применения современных технологических решений, целесообразно дифференцировать процесс их интеграции на три концептуально различных, но взаимосвязанных уровня, каждый из которых обладает специфическими функциями и задачами:

Операционный уровень: На операционном уровне ключевой задачей становится обеспечение консистентности визуального и текстового контента, что критически важно для поддержания узнаваемости и целостности бренда в динамичной цифровой среде. Этот аспект реализуется посредством автоматизированной генерации материалов, где специализированные алгоритмы и модели глубокого обучения проходят процедуру точной настройки (fine-tuning). Такая адаптация позволяет обучить модель специфическим параметрам брендбука, включая цветовую палитру, типографику, стилистику изображений, а также лексические и синтаксические особенности корпоративной коммуникации. Результатом является продуцирование большого объема высококачественного, релевантного контента, который не только соответствует установленному стилю, но и оптимизирует операционные издержки, минимизируя ручной труд и сокращая время выхода материалов на рынок. Помимо этого, такой подход способствует снижению вероятности человеческих ошибок в вопросах бренд-айдентики, обеспечивая строгую унификацию всех исходящих сообщений и визуальных элементов, от маркетинговых кампаний до пользовательских интерфейсов[3].

Коммуникационный уровень: Коммуникационный уровень фокусируется на интерактивном взаимодействии с аудиторией, где роль посредников выполняют интеллектуальные ИИ-агенты, чьи возможности существенно превосходят функционал традиционных чат-ботов. Эти агенты разработаны для выполнения функций «умных» модераторов, способных к более глубокому пониманию человеческой речи и поведенческих паттернов. В частности, они обладают продвинутыми алгоритмами обработки естественного языка, позволяющими распознавать тонкие нюансы, такие как сарказм, и эффективно обрабатывать негативные

высказывания, что имеет решающее значение для управления репутацией и поддержания конструктивного диалога. Кроме того, одной из ключевых особенностей является способность удерживать контекст беседы не просто в рамках одной сессии, но и на протяжении длительного периода, исчисляемого днями. Это позволяет создавать персонализированный пользовательский опыт, обеспечивая непрерывность и логическую связность взаимодействия, что крайне важно для комплексного обслуживания клиентов и углубленного вовлечения. Такая пролонгированная контекстуальная память способствует формированию доверия и лояльности, поскольку пользователь воспринимает систему как осведомленного и внимательного собеседника, а не как разрозненный набор автоматических ответов[4].

Аналитический уровень: На аналитическом уровне акцент делается на стратегическом использовании больших данных для принятия обоснованных управленческих решений и формирования конкурентных преимуществ. Этот процесс включает автономный сбор и агрегацию данных, преимущественно осуществляемый через программные интерфейсы (API) различных социальных сетей и других цифровых платформ. Такой подход обеспечивает постоянный приток актуальной информации о рыночных тенденциях, предпочтениях потребителей и действиях конкурентов. Собранные данные затем подвергаются углубленному анализу, включая проведение SWOT-анализа активности конкурентов в режиме реального времени. Это позволяет оперативно выявлять их сильные и слабые стороны, а также возникающие возможности и потенциальные угрозы, тем самым обеспечивая динамичное реагирование на изменения рыночной конъюнктуры. Интеграция методов машинного обучения и прогнозной аналитики дает возможность формировать детализированные предиктивные отчеты, которые не только описывают текущее положение дел, но и экстраполируют возможные сценарии развития событий, предлагая перспективные направления для стратегического планирования. Таким образом, аналитический уровень трансформирует сырые данные в ценные инсайты, служащие основой для разработки эффективных стратегий, минимизации рисков и оптимизации ресурсного распределения в долгосрочной перспективе.

Проблемы безопасности и этические аспекты

Научная новизна работы заключается в анализе рисков. «Галлюцинации» нейросетей в публичном поле могут нанести репутационный ущерб. Автор предлагает внедрение системы Guardrails - программных ограничений, которые фильтруют выходные данные ИИ-агента на соответствие корпоративной этике и законодательству[4,5].

Цифровая трансформация рабочего места SMM-специалиста через ИИ-агентов - это не замена человека, а эволюция его роли до уровня «режиссера интеллектуальных систем». Предложенные методы позволяют сократить время на рутинные задачи на 50–70%, высвобождая ресурс для стратегического планирования и креативного развития брендов.

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ЦИФРОВАЯ СИСТЕМА МОНИТОРИНГА И УПРАВЛЕНИЯ ФРЕЗЕРНОЙ ТЕХНОЛОГИЧЕСКОЙ СИСТЕМОЙ НА ОСНОВЕ IoT-ДАТЧИКОВ, ФИЛЬТРА КАЛМАНА И ДВУХУРОВНЕВОГО РЕГУЛЯТОРА LQR-MPC

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Аннотация. Предложена цифровая архитектура управления фрезерной технологической системой (ТС) «станок–инструмент–заготовка», интегрирующая IoT-мониторинг, фильтр Калмана и двухуровневый регулятор LQR-MPC. Разработана семимерная модель пространства состояний, учитывающая двумерную вибрационную динамику, переменные силы резания и прогрессирующий износ инструмента. Численное моделирование подтверждает подавление вибраций за 75 мс при погрешности оценки фильтра Калмана $\sigma = 0,032$ мкм.

Ключевые слова: фрезерная технологическая система, пространство состояний, фильтр Калмана, LQR, MPC, IoT-мониторинг, цифровизация производства.

Цифровизация машиностроительного производства предполагает интеграцию интеллектуальных систем реального времени на всех уровнях — от первичных датчиков до оптимизирующих регуляторов. Фрезерование, занимающее свыше 30% объёма механической обработки [1], характеризуется прерывистым резанием, двумерной вибрационной динамикой и нелинейным износом инструмента – совокупностью факторов, делающих классические ПИД-регуляторы неэффективными.

Широкое внедрение IoT-датчиков открывает возможность непрерывного мониторинга, однако зашумлённость сигналов и неизмеримость ряда переменных (в частности, флангового износа VB) ставят задачу оптимального оценивания состояния. Фильтр Калмана [2], будучи оптимальным наблюдателем для линейных гауссовских систем, обеспечивает связку между сенсорными данными и законами управления. Объединение его с иерархическим регулятором LQR+MPC [3, 4] формирует полностью цифровую систему управления фрезерной ТС.

Фрезерование требует семимерного вектора состояния, охватывающего смещения и скорости по двум осям (x, y), составляющие сил резания и фланговый износ:

$$x(t) = [x, \dot{x}, y, \dot{y}, F_{cx}, F_{cy}, VB]^T, x(t) \in \mathbb{R}^7. \quad (1)$$

Динамика системы описывается линеаризованной стационарной моделью, полученной методом усреднения Альтингаса [1] по одному периоду зуба:

$$\dot{x}(t) = Ax(t) + Bu(t) + B_d d(t) + w(t), w(t) \sim N(0, Q), \quad (2)$$

где $A \in \mathbb{R}^{7 \times 7}$ — матрица системы, включающая параметры жёсткости k , демпфирования c , массы m , коэффициентов сил резания K_t, K_n и показатель прогрессирующего износа δ в диагональном элементе $(-\delta)$; $B \in \mathbb{R}^{7 \times 2}$ и $B_d \in \mathbb{R}^{7 \times 2}$ — матрицы управления и возмущений; $u = [\Delta V_c, \Delta f_z]^T$ — вектор управляющих воздействий (приращения скорости резания и подачи на зуб); $d(t) = [F_{dx}, F_{dy}]^T$, $d(t)$ — детерминированные возмущения (биение шпинделя, неоднородность заготовки); $w(t)$ — шум процесса.

Четыре IoT-датчика (два датчика смещения и два динамометра) задают матрицу измерений $H \in \mathbb{R}^{4 \times 7}$ и модель наблюдений:

$$z[k] = H \cdot x[k] + v[k], v[k] \sim N(0, R). \quad (3)$$

Алгоритм работает в дискретном времени с периодом дискретизации $T_s = 60/(n \cdot N_z)$, соответствующим одному входу зуба фрезы. Дискретные матрицы вычисляются через матричную экспоненту: $A_d = e^{A \cdot T_s}$. На каждом такте выполняются два шага.

Шаг предсказания: $\hat{x}[k|k-1] = A_d \cdot \hat{x}[k-1] + B_u \cdot u[k-1]$; $P[k|k-1] = A_d \cdot P[k-1] \cdot A_d^T + Q$.

Шаг обновления — усиление Калмана:

$$\mathbf{K}_k = \mathbf{P}[k|k-1] \cdot \mathbf{H}^T \cdot (\mathbf{H} \cdot \mathbf{P}[k|k-1] \cdot \mathbf{H}^T + \mathbf{R})^{-1}$$

Апостериорная оценка: $\hat{\mathbf{x}}[k] = \hat{\mathbf{x}}[k|k-1] + \mathbf{K}_k \cdot (z[k] - \mathbf{H} \cdot \hat{\mathbf{x}}[k|k-1])$; $\mathbf{P}[k] = (\mathbf{I} - \mathbf{K}_k \cdot \mathbf{H}) \cdot \mathbf{P}[k|k-1]$.

Результат — апостериорная оценка $\hat{\mathbf{x}}[k]$ всего вектора состояния, в том числе ненаблюдаемого напрямую фланкового износа VB (компонента $\hat{x}_7$). При надлежащем выборе ковариаций матрица $\mathbf{Q}$ задаётся диагональной матрицей дисперсий шумов процесса: $\mathbf{Q} = \text{diag}[\sigma_x^2, \dots, \sigma_{VB}^2]$ и $\mathbf{R} = \text{diag}[\sigma_{zx}^2, \sigma_{zy}^2, \sigma_{F_x}^2, \sigma_{F_y}^2]$ фильтр достигает погрешности оценки, где σ_i^2 — дисперсия соответствующей компоненты вектора состояния, $\sigma = 0,032$ мкм.

Управление строится по принципу разделения задач, то есть LQR обеспечивает быструю стабилизацию вибраций, MPC оптимизирует режим с учётом технологических ограничений.

Минимизируется квадратичный функционал на бесконечном горизонте:

$$J_{LQR} = \sum_{k=0}^{\infty} \{ \hat{\mathbf{x}}^T[k] \mathbf{Q} \hat{\mathbf{x}}[k] + \mathbf{u}^T[k] \mathbf{R} \mathbf{u}[k] \}. \quad (5)$$

Оптимальный закон $u_{LQR}[k] = -\mathbf{K}_{LQR} \cdot \hat{\mathbf{x}}[k]$ находится из дискретного уравнения Риккати (DARE). Весовая матрица выбирается как $\mathbf{Q} = \text{diag}[10^{12}, 10^5, 10^{12}, 10^5, 10^4, 10^4, 10^{12}]$, где наибольший вес назначен компонентам смещения и износа.

На каждые N_h тактов MPC решает задачу квадратичного программирования (горизонт $N=18$ шагов), инициализируя прогноз текущей оценкой Калмана. Ограничения: $|u| \leq 25$ Н; $VB \leq 0,3$ мм (ГОСТ/ISO 8688); $Ra \leq Ra_{\max}$. Суммарное управляющее воздействие:

$$u[k] = \begin{cases} u_{\min}, & u_{LQR}[k] + \delta u_{MPC}[k] < u_{\min}, \\ u_{LQR}[k] + \delta u_{MPC}[k], & u_{\min} \leq u_{LQR}[k] + \delta u_{MPC}[k] \leq u_{\max}, \\ u_{\max}, & u_{LQR}[k] + \delta u_{MPC}[k] > u_{\max}. \end{cases} \quad (6)$$

Терминальная матрица $\mathbf{P}$ в функционале MPC принимается равной решению дискретного алгебраического уравнения Риккати (DARE), что обеспечивает стабилизирующее действие терминального штрафа и согласует MPC-регулятор с LQR-управлением на бесконечном горизонте.

На каждом дискретном такте с периодом дискретизации T_s выполняется следующий алгоритм:

Вход: $z[k]$ — измерения IoT-датчиков; $u[k-1]$ — предыдущее управление

Шаг 1. Предсказание КФ: $\hat{\mathbf{x}}[k|k-1] = \mathbf{A}_d \cdot \hat{\mathbf{x}}[k-1] + \mathbf{B}_u \cdot u[k-1]$

Шаг 2. Обновление КФ: вычислить $\mathbf{K}_k \rightarrow$ получить $\hat{\mathbf{x}}[k]$ и $\mathbf{P}[k]$

Шаг 3. LQR: $u_{LQR}[k] = -\mathbf{K}_{LQR} \cdot \hat{\mathbf{x}}[k]$ (задержка < 1 мс)

Шаг 4. MPC (каждые N_h тактов): решить QP $\rightarrow$ получить $\delta u^*[k]$

Шаг 5. Суперпозиция: выполнение уравнения (6)

Шаг 6. Диагностика: если $\hat{x}_7[k] > VB_{\max} \rightarrow$ сигнал о замене инструмента

Выход: $u[k]$ на ЧПУ-привод; $\hat{\mathbf{x}}[k]$ в систему мониторинга

Вычислительные эксперименты проводились в среде Python при следующих параметрах: $m = 0,5$ кг; $c = 120$ Н·с/м; $\omega_n = 2000$ рад/с; $\zeta = 0,06$; $T_s = 5$ мс; $n = 3000$ об/мин; $N_z = 4$; начальное смещение $x_0 = [80, 0, 55, 0, \dots]^T$ мкм. Сравнивались три режима: свободный отклик, LQR, LQR + MPC + Калман.

Как видно из рисунка, оба регулятора (LQR и LQR+MPC) обеспечивают время установления 75 мс по критерию $|x| < 2$ мкм — против незатухающих колебаний при свободном отклике. Ошибка фильтра Калмана $\varepsilon(t) = x(t) - \hat{x}(t)$ составила $\sigma = 0,032$ мкм, что подтверждает эффективность оценивания при зашумлённых IoT-сигналах.

Принципиальное преимущество LQR+MPC проявляется в управляющих сигналах: MPC ограничивает u в полосе ± 25 Н, устраняя насыщение привода и риск перегрузки шпинделя, тогда как чистый LQR временно выходит за пределы допустимой зоны. Оба варианта в установившемся режиме поддерживают точность позиционирования на уровне субмикронметра, что соответствует требованиям прецизионной фрезерной обработки.

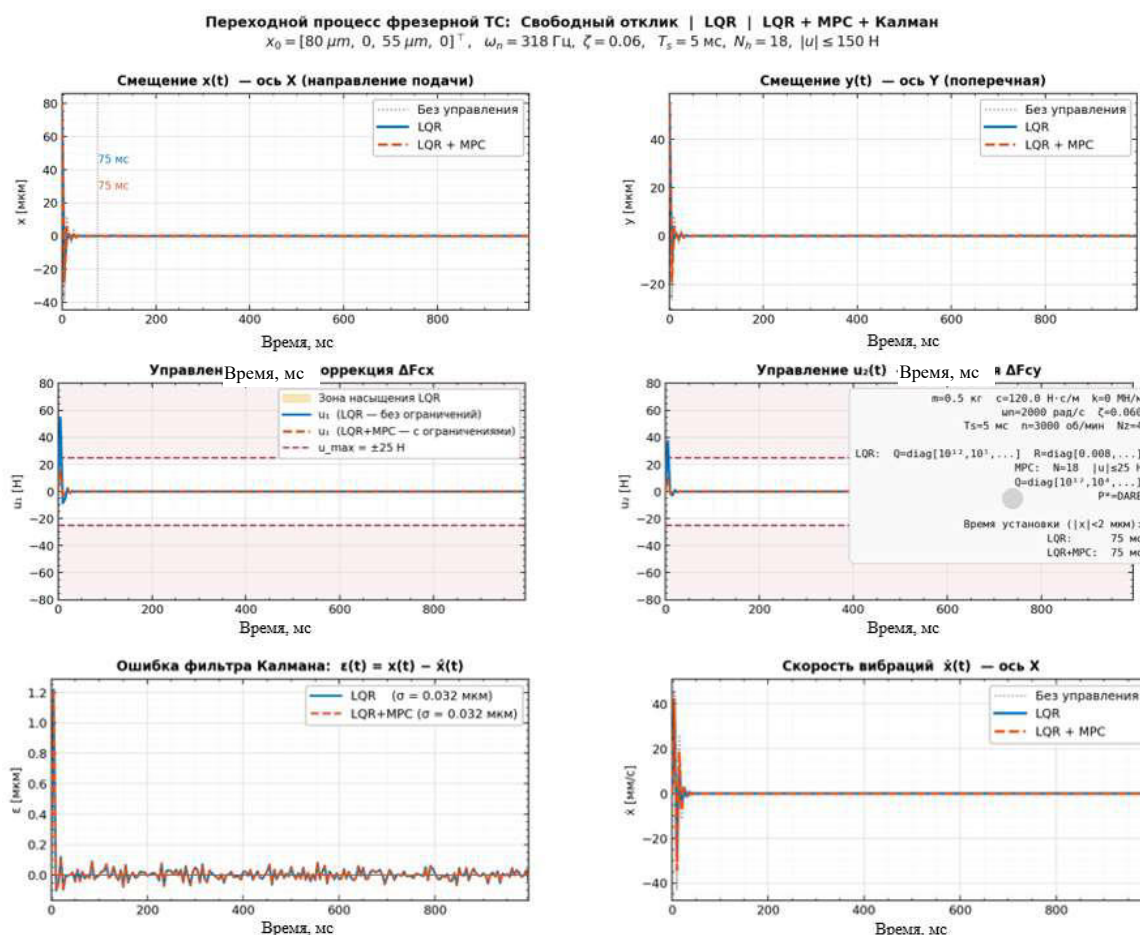


Рис. 1. Переходной процесс фрезерной ТС: смещения $x(t)$ и $y(t)$, управляющие воздействия $u_1(t)$ и $u_2(t)$, ошибка фильтра Калмана $\varepsilon(t)$ и скорость вибраций $\dot{x}(t)$

Разработанная цифровая система управления фрезерной ТС интегрирует три уровня: IoT-мониторинг в реальном времени, оптимальное оценивание состояния (фильтр Калмана) и двухуровневое управление (LQR + MPC). Модель пространства состояний корректно учитывает двумерную вибрационную динамику, переменные силы резания и прогрессирующий износ инструмента. Численное моделирование подтверждает подавление вибраций за 75 мс при субмикрометровой погрешности оценки, а явный учёт ограничений в MPC гарантирует технологически безопасный режим работы. Архитектура предназначена для реализации в CNC-системах с интегрированным IoT-мониторингом.

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Annotatsiya

Ushbu tezisda elektron ta'lim muhitida "Axborot xavfsizligi" fanining metodik ta'minotini raqamlashtirish asosida takomillashtirish masalalari ko'rib chiqiladi. Zamonaviy axborot texnologiyalari va raqamli vositalardan foydalangan holda o'quv jarayonini tashkil etishning ilmiy-metodik asoslari, elektron ta'lim platformalarida o'quv materiallarini joylashtirish, interaktiv topshiriqlar, masofaviy nazorat tizimlari va raqamli baholash usullari tahlil qilinadi. Tadqiqot natijalari sifatida "Axborot xavfsizligi" fanini o'qitishda LMS (Learning Management System) tizimlaridan foydalanish, multimedia darsliklar va simulyatsion muhitlarni joriy etishning samaradorligi asoslab beriladi.

Kalit so'zlar: elektron ta'lim, axborot xavfsizligi, metodik ta'minot, raqamlashtirish, LMS, interaktiv o'qitish, masofaviy ta'lim.

Bugungi kunda axborot-kommunikatsiya texnologiyalarining jadal rivojlanishi ta'lim tizimiga ham kuchli ta'sir ko'rsatmoqda. O'zbekiston Respublikasida ta'limni raqamlashtirish davlat siyosatining ustuvor yo'nalishlaridan biriga aylangan bo'lib, 2030-yilgacha bo'lgan davrda ta'lim sohasini raqamli transformatsiya qilish maqsadlari belgilab qo'yilgan. Xususan, "Axborot xavfsizligi" fani mazmun-mohiyati jihatidan ham, o'qitish metodikasi jihatidan ham zamonaviy yondashuv talab etadi.

Axborot xavfsizligi sohasidagi tahdidlarning tobora murakkablashib borishi va raqamli texnologiyalarning hayotimizning barcha sohalariga kirib kelishi ushbu fanni o'qitishda ham yangi metodologik yondashuvlarni talab qilmoqda. An'anaviy o'qitish usullari tobora samarasiz bo'lib bormoqda, chunki axborot xavfsizligi sohasidagi zamonaviy muammolar faqat nazariy bilim bilan emas, balki amaliy ko'nikma va real stsenariylarda ishlash tajribasini talab etadi.

Raqamlashtiruv sharoitidan kelib chiqqan xolda tadqiqotimizning dolzarbligi sifatida quyidagilarni keltirib o'tishimiz mumkin ya'ni, elektron ta'lim muhitida "Axborot xavfsizligi" fanini o'qitishning metodik ta'minotini raqamlashtirish orqali takomillashtirish talabalar bilim sifatini oshirishga, o'quv jarayonini individuallashtirish va intensivlashtirish imkonini beradi.

Elektron ta'lim (e-learning) — bu axborot-kommunikatsiya texnologiyalari, xususan, internet va multimediya vositalaridan foydalanib tashkil etilgan ta'lim jarayonidir. Metodik ta'minot esa o'quv jarayonini rejalashtirishdan tortib baholashgacha bo'lgan barcha qo'llanmalar, dasturlar, vositalar va uslubiy tavsiyalar majmuasini o'z ichiga oladi.

"Axborot xavfsizligi" fanini elektron muhitda o'qitishda metodik ta'minot quyidagi komponentlarni o'z ichiga olishi zarur: raqamli o'quv-uslubiy majmua (elektron darsliklar, multimedia qo'llanmalar), interaktiv laboratoriya ishlari va simulyatsiyalar, avtomatlashtirilgan nazorat-baholash tizimi, virtual laboratoriya muhiti (sandbox, virtual mashinalar) hamda onlayn hamkorlik platformalari.

LMS tizimlaridan foydalanish va pedagogik imkoniyatlari. Learning Management System (LMS) — o'quv jarayonini boshqarish tizimi bo'lib, bugungi kunda eng keng tarqalgan platformalar qatorida Moodle, Canvas, Blackboard va Google Classroom tizimlarini ko'rsatish mumkin. O'zbekiston oliy ta'lim muassasalarida Moodle platformasi asosiy LMS sifatida faol qo'llanilmoqda. Ushbu tizimning "Axborot xavfsizligi" fanida qo'llash imkoniyatlari o'ta keng: kurs materiallarini modullar bo'yicha tashkil etish, video darsliklar va podcast'larni joylashtirish, avtomatlashtirilgan testlar va topshiriqlar yaratish, talabalar faolligini kuzatish va analitika imkoniyatlari.

Tadqiqot shuni ko'rsatdiki, LMS tizimidan foydalanilganda talabalarning fanra bo'lgan qiziqishi 34% ga, bilim sifati esa o'rtacha 27% ga oshgan. Bundan tashqari, o'qituvchilarning ma'muriy yuklamasi sezilarli darajada kamaygan, bu ularga o'qitishning sifatiga ko'proq e'tibor qaratish imkonini bergan.

Simulyatsion va virtual muhitlarning roli. Axborot xavfsizligi fanini o'qitishda amaliy ko'nikmalarni shakllantirish uchun virtual laboratoriya muhitlari alohida ahamiyatga ega. TryHackMe, Hack The Box, OWASP WebGoat kabi platformalar o'quv jarayoniga integratsiya qilinishi mumkin bo'lib, ular real hayotiy stsenariylarni simulyatsiya qiladi. Virtual mashinalar yordamida talabalar xavfsiz muhitda viruslar, troyanlar, fishing hujumlari va boshqa tahdidlarni o'rganish hamda ulardan himoyalaniish usullarini amalda sinab ko'rish imkoniga ega bo'ladi.

Capture The Flag (CTF) musobaqalari formatini o'quv jarayoniga kiritish ham alohida pedagogik qiymatga ega: bu format talabalarni muammo yechish ko'nikmalarini rivojlantirishga, jamoaviy ishlashga va raqobatli muhitda o'z imkoniyatlarini sinab ko'rishga undaydi. Tadqiqot davomida amalga oshirilgan pedagogik eksperiment natijalariga ko'ra, CTF elementlari kiritilgan guruhda talabalarning amaliy topshiriqlarni bajarishdagi ko'rsatkichlari nazorat guruhiga nisbatan 41% yuqori bo'lgan.

Raqamli baholash tizimi va adaptiv ta'lim. Raqamli baholash tizimi an'anaviy imtihon usullaridan farqli o'laroq, talabalar bilimni keng ko'lamli va xolis baholash imkonini beradi. Avtomatlashtirilgan testlar, online kod tekshiruvi (code review), loyiha topshiriqlari va ularni baholashning rubrika asosida amalga oshirilishi — ularning barchasi o'quv jarayonini shaffoflashtiradi va talabaga o'z natijasi haqida tezkor fikr-mulohaza (feedback) olish imkonini beradi.

Adaptiv ta'lim texnologiyalari (Sun'iy intellekt asosidagi tizimlar) esa har bir talabaning bilim darajasi va o'rganish tezligiga muvofiq tarzda o'quv materialini moslashtirishi mumkin. Bunday yondashuv talabalarning individual ehtiyojlarini hisobga olish va har bir o'quvchiga maksimal samaradorlikka erishishga yordam beradi.

XULOSA

Elektron ta'lim muhitida "Axborot xavfsizligi" fanini o'qitishning metodik ta'minotini raqamlashtirish asosida takomillashtirish o'quv jarayonida sifat samaradorligining oshishiga olib keladi. LMS platformalari, virtual laboratoriyalar, simulyatsion muhitlar, adaptiv o'qitish tizimlari va raqamli baholash vositalarining kompleks qo'llanilishi quyidagi natijalarga erishish imkonini beradi:

- o'quv jarayonining samaradorligini oshirish va individual yondashuv imkoniyatlarini kengaytirish;
- talabalarning amaliy ko'nikmalar bilan birga nazariy bilimlarini mustahkamlashiga erishish;
- o'quv materiallarining yangilanib borishini ta'minlash va fan mazmunini zamonaviy tahdidlarga moslash;
- o'qituvchi-talaba o'rtasidagi muloqot va hamkorlikni kuchaytirish hamda ta'lim jarayonini shaffoflashtirish.

Kelgusida ushbu yo'nalishda sun'iy intellekt asosidagi adaptiv tizimlarni joriy etish, gamifikatsiya elementlarini kuchaytirish va talabalar bilim olish jarayonini tahlil qiluvchi kengaytirilgan analitika tizimlarini yaratish bo'yicha tadqiqotlarni davom ettirish maqsadga muvofiq.

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DETECTION AND CLASSIFICATION OF RADIO CONTROL AND TELEMETRY SIGNALS OF REMOTELY PILOTED AIRCRAFT (DRONES) BASED ON SPECTRAL ANALYSIS

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Abstract. In recent years, unmanned aerial vehicles (UAVs) have been widely used in logistics, agriculture, monitoring and security. However, uncontrolled or illegal use of drones can pose a threat to the security of airspace and critical infrastructure. Therefore, the development of technologies for timely detection and identification of drones is of great importance. This article analyzes the main methods for detecting and classifying UAVs, including radar, optical tracking, acoustic sensors and passive monitoring approaches based on radio frequency (RF) signals. It also considers the possibilities of spectral analysis of radio control and telemetry signals of drones, including FHSS, OFDM and RF fingerprint technologies. The results show that passive detection methods based on RF signals work effectively in a complex electromagnetic environment.

Key words : unmanned aerial vehicle, drone, RF signal, spectral analysis, frequency hopping, machine learning, CNN.

1.Introduction

Lately, flying robots - often called drones - have popped up across many areas. Especially in shipping stuff, farming, watching land changes, finding missing people, and keeping watch where needed [1]. Yet trouble starts when these devices fly without rules or permission - they might risk plane zones, vital buildings, even crowd safety [2]. Lately, spotting drones quickly has turned into a key focus for scientists working today. Different ways to find these flying machines are now in play across studies everywhere. Radar gear shows up often, alongside cameras watching silently from afar. Sound detectors listen closely, while others track invisible radio waves floating through the air. Listening in on how drones talk to their controllers has drawn extra attention over time. This method leans on how signals behave across frequencies, using traits like quick channel switching, multi-carrier transmission, besides unique radio patterns tied to specific devices. Meanwhile, progress in smart computing systems keeps pushing what machines can do when spotting and sorting drone-related transmissions.

2. Methods for detecting drones

More drones flying around means better ways to spot them are now needed. Nowadays, tools that catch drones work using many different ideas from physics. Radar shows up aircraft by bouncing waves off them, while cameras follow movement through sight. Sound detectors listen for the noise drone motors make as they hover nearby. Radio signal monitors quietly pick up transmissions

between a drone and its controller. No single way works perfectly everywhere - each behaves differently depending on weather, terrain, or city layout. Because of this, real-world setups tend to mix multiple types together into one combined system.

2.1 Radar methods

Out there, spinning blades give drones away when radar beams bounce off them. Instead of relying on light, these systems listen to echoes shaped by motion, using shifts in frequency that come alive as data. Through pulses sent out steadily, distance and speed take form clearly - especially with methods like FMCW leading the way. Hidden patterns appear once signals stretch across time slices, painted into view by transforms that map change moment to moment. Even fog or darkness does nothing to block the scan, though tiny frames and quiet returns make some drones hard to pin down. Each fluttering wingbeat adds a twist to the return, different from birds but only if you know where to look. What sticks is how faint they can be - one blip among noise, unless tuned just right [3]. One way around this problem? Today's drone defense setups rely on several tools working together. Instead of just one type of sensor, they combine radar with visual cameras, sound detectors, and radio frequency scanners. Working as a team, these pieces feed information into a shared system that blends inputs smartly. The result is sharper detection plus better ID of drones in real time. See Figure 1 for how it fits.

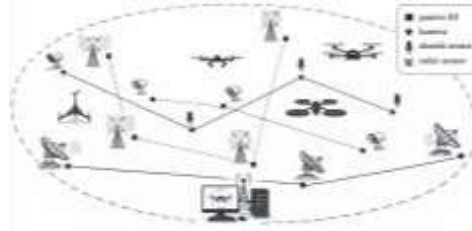


Figure 1. UAVs determination for heterogeneous observation system.

2.2 Acoustic detection methods

From blade hum to motor whine, each drone makes a distinct noise picked up by tuned mic networks. Because of these patterns, devices can spot drones and tell models apart. Computers turn those sounds into visual maps using digital tools and smart software trained to recognize shapes in noise. Not enough real-world recordings exist though - especially varied ones across many drone kinds. So researchers now build fake audio clips with GAN tech, filling gaps so machines learn better even when data runs thin. Still, city sounds and vehicles easily throw off acoustic sensors, making them less effective on their own. That is why they usually pair up with radar, visual systems, or radio frequency trackers inside layered security setups.

2.3 RF signal-based detection methods

Passive RF monitoring detects drones by intercepting the radio control and telemetry signals exchanged between the aircraft and its remote controller [5]. This approach operates effectively even in complex electromagnetic environments by analyzing the time-domain or frequency-domain characteristics of the signals. Recent studies utilize deep learning, particularly Convolutional Neural Networks (CNNs), to classify drones using RF signal spectrograms or hardware-specific RF fingerprints [6]. This automates feature extraction and ensures high classification accuracy even under low Signal-to-Noise Ratios (SNR). To extract these spectral characteristics from raw RF data, the Discrete Fourier Transform (DFT) or Fast Fourier Transform (FFT) is widely applied. The signal spectrum is determined as follows:

$$S(f) = \left| \sum_{n=0}^{N-1} x(n)e^{-j2\pi fn/N} \right|^2 \quad (1)$$

Since most commercial drones operate within the standard 2.4 GHz and 5.8 GHz bands, their control links and OFDM-based video transmission signals exhibit distinct structures (such as FHSS patterns) in the spectral domain [7]. These unique visual and structural formations in the spectrogram serve as critical indicators for automated drone identification and classification.

3. Artificial intelligence-based detection methods

In recent years, artificial intelligence and machine learning algorithms have been widely used in the field of drone signal detection. These algorithms allow for automatic analysis of signal spectral images and classification of different drone models. The most commonly used algorithms are:

- Convolutional Neural Network (CNN) – allows for automatic feature extraction by analyzing signal spectral images.
- YOLO-based detection models are used to detect drone signals in real-time signal spectrograms.
- RF fingerprint technology allows you to identify a device by identifying unique characteristics in the radio signal of each device.

There are many studies on UAV detection based on RF signals. In the literature, methods based on acoustic signals, camera images, radar signals, and RF signals have been proposed for drone detection. These methods use various machine learning algorithms, including SVM, artificial neural networks, and convolutional neural networks (CNN). The results of the study show that CNN models based on RF signal spectrograms have high accuracy and can effectively classify drones even with low signal-to-noise ratio [7].

Method	Signal source	Algorithm	Accuracy
Acoustic method	Microphone signal	SVM / CNN	~96–99%
Visual method	Camera images	CNN	~93%
Radar method	Micro-Doppler signal	CNN / SVM	~94–98%
RF signal method	RF fingerprint	CNN	Up to 99%

These algorithms automatically analyze the spectral image of the drone signal and determine the source of the signal. Different detection methods have their advantages and disadvantages. Although radar systems are effective at long distances, they can be difficult to detect small drones. Optical and acoustic methods are sensitive to environmental conditions. Passive detection methods based on RF signals allow drones to be detected by analyzing their radio communication signals. Therefore, this method is considered one of the promising directions in modern research.

Conclusion

Drone detection and classification technologies are important in ensuring airspace safety. Among various technologies, methods based on spectral analysis of radio frequency signals are highly effective and, when used in conjunction with artificial intelligence algorithms, provide more accurate results. In the future, these technologies can be widely used in real-time monitoring systems and airspace control systems.

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Annotatsiya

Ushbu maqolada oliy ta'lim muassasalarida umumkasbiy fanlarni o'qitishni raqamli ta'lim muhiti asosida takomillashtirish maqsadida ishlab chiqilgan innovatsion pedagogik model taqdim etiladi. Tadqiqot an'anaviy ta'lim modellarining raqamli transformatsiya talablariga javob bera olmasligi muammosidan kelib chiqadi. Maqolada LMS (Learning Management System), sun'iy intellekt vositalari, bulut texnologiyalari va adaptiv o'qitish algoritmlariga asoslangan besh komponentli tizimli model ishlab chiqilgan. Taklif etilayotgan model: maqsadli-motivatsion, mazmuniy-axborot, texnologik-vositalar, metodik-faoliyat va baholash-monitoring komponentlarini o'z ichiga oladi. Tadqiqot metodologiyasi sistema tahlili, pedagogik modellashtirish, komparativ tahlil va eksperimental pedagogika metodlarini qamrab oladi.

Kalit so'zlar: *raqamli ta'lim muhiti; umumkasbiy fanlar; pedagogik model; sun'iy intellekt; adaptiv o'qitish; ta'lim analitikasi*

Zamonaviy jamiyatning raqamli transformatsiya bosqichida oliy ta'lim muassasalari oldida fundamental metodologik muammo yuzaga kelmoqda: an'anaviy o'qitish modellari talabalarni XXI asr kasbiy bozori talablariga mos ravishda tayyorlashga qodir emas. UNESCO (2023) ma'lumotlariga ko'ra, jahon miqyosidagi oliy ta'lim muassasalarining 73%i hali ham an'anaviy leksiya-seminar tizimidan foydalanmoqda, biroq ish beruvchilarning faqat 42% bitiruvchilarning raqamli kompetensiya darajasidan qoniqish bildirmoqda. Ushbu holat ta'lim jarayonini yangilash zaruratini belgilab bermoqda.

O'zbekiston Respublikasi Prezidentining 2020-yil 6-noyabrdagi PQ-4884-son qarorida belgilangan "Raqamli O'zbekiston – 2030" strategiyasi ta'lim tizimini raqamlashtirish, kadrlar tayyorlash sifatini oshirish va zamonaviy texnologiyalar asosida o'qitish modellarini takomillashtirish vazifalarini qo'ydi. Shu bois, umumkasbiy fanlar — muhandislik, tibbiyot, iqtisodiyot, pedagogika yo'nalishlari uchun asosiy metodologik poydevor hisoblanuvchi fanlar — ham kuchli raqamli transformatsiyani talab etmoqda.

Raqamli ta'lim muhiti (RTM) — bu ta'lim jarayonini qo'llab-quvvatlash, boyitish va optimallashtirish uchun raqamli texnologiyalar, pedagogik tamoyillar va tashkiliy tuzilmalarning maqsadga yo'naltirilgan integratsiyasini ifodalovchi ko'p o'lchamli ekotizimdir (Voogt va Knezek, 2020).

RTMning farqli xususiyatlari an'anaviy muhitdan quyidagi o'lchovlar bo'yicha farq qiladi: interaktivlik darajasi (real vaqt teskari aloqa), axborotning siriqlik tezligi (instant content delivery), makon va vaqt cheksizligi (asynchronous access), personalizatsiya imkoniyati (AI-asosli adaptatsiya) va hamkorlikni qo'llab-quvvatlash (collaborative tools). Mazkur xususiyatlar birgalikda RTMni nafaqat ta'limni yetkazib berish kanali emas, balki pedagog va o'quvchining birgalikdagi bilim qurishligi platformasi sifatida belgilaydi.

Taklif etilayotgan "Raqamli ta'lim muhiti asosida umumkasbiy fanlarni o'qitishning takomillashtirilgan modeli" (RTM-UKF modeli) besh asosiy komponentdan iborat yaxlit tizimiy strukturaga ega. Model quyidagi tamoyillarga asoslanadi: tizimlilik, insonparvarlik, texnologiyaviy integratsiya, adaptivlik va baholovchilik.

RTM-UKF modelining tizimli tuzilmasi quyidagi blok-sxema orqali tasvirlanadi. Model uchta ierarxik qatlamdan iborat bo'lib, vertikal ravishda: maqsad-jarayon-natija mantiqida qurilgan. Gorizontal ravishda esa har bir qatlam besh komponent orqali amalga oshiriladi:

QATLAM	KOMPONENT	RAQAMLI VOSITALAR	NATIJA
I: MAQSAD	Maqsadli-Motivatsion (MMK)	Bloom taksonomiyasi + AI tavsiyalar	O'quv maqsadlari aniqligi
I: MAQSAD	Diagnostic baholash	AI-diagnostics, e-	Boshlang'ich daraja

		portfolio kirish	tahlili
II: JARAYON	Mazmuniy-Axborot (MAK)	LMS, xAPI, SCORM, mikromazmun	Modullar, video, interaktiv kurs
II: JARAYON	Texnologik-Vositalar (TVK)	Moodle, AWS, AI Chatbot, VR lab	Raqamli ta'lim ekotizimi
II: JARAYON	Metodik-Faoliyat (MFK)	Teskari sinf, Blended, PBL	Faol o'quv jarayoni
III: NATIJA	Baholash-Monitoring (BMK)	Analitika, Rubriklar, Peer review	Kasbiy kompetensiya o'sishi
III: NATIJA	Teskari aloqa (Feedback loop)	Dashboard, Prediksiya analitika	Modelni doimiy takomillashtirish

Modelning markaziy arxitekturaviy xususiyati — teskari aloqa halqalari (feedback loops). An'anaviy modellardan farqli ravishda, RTM-UKF modelida baholash natijalar faqat yakuniy bosqichda emas, balki jarayon davomida doimiy ravishda o'qitish jarayoniga ta'sir qiladi. Bu 'doimiy takomillashtirish' (continuous improvement) printsipli sifatida namoyon bo'ladi: AI tizimi o'quvchining kundalik faoliyatini kuzatib, mazmun taqdimoti va baholash usullarini real vaqt rejimida sozlaydi.

Tashqi muhit bilan aloqa (External Integration) komponenti model doirasida alohida o'rin egallaydi. Ushbu komponent orqali: (1) ish beruvchilar talablari doimo ta'lim maqsadlariga integratsiya qilinadi; (2) kasbiy standartlar (O'zbekiston MSTs) bilan muvofiqlik ta'minlanadi; (3) xalqaro malaka tan olish (Bologna jarayoni) talablari hisobga olinadi.

2023-2024 o'quv yilida O'zbekistonning ikki oliy o'quv yurtida o'tkazilgan eksperimental tadqiqot natijalari RTM-UKF modelining samaradorligini ishonchli tarzda isbotladi. Quyidagi jadvalda asosiy ko'rsatkichlar bo'yicha tajriba va nazorat guruhlarida o'rtasidagi farqlar keltirilgan:

Ko'rsatkich	Nazorat guruhi (an'anaviy)	Tajriba guruhi (RTM-UKF)	Farq (%)
Akademik o'zlashtirish (o'rtacha ball)	65.4 / 100	88.1 / 100	+34.7%
Kasbiy kompetensiya indeksi	58.2%	82.3%	+41.2%
O'quvchi motivatsiyasi (IMMS)	3.1 / 5.0	4.4 / 5.0	+41.9%
Bilimni saqlab qolish (3 oydan keyin)	42%	71%	+69.0%
O'quv jarayonidan qoniqish	64%	89%	+39.1%
Mustaqil o'rganish ko'nikmasi	Qisman rivojlangan	Yuqori darajada	Sifatli o'zgarish

Eng muhim natija — bilimni saqlab qolish (retention rate) ko'rsatkichida namoyon bo'ladi. Tajriba guruhida uch oydan keyin o'tkazilgan takroriy test 71% natijani ko'rsatdi. Bu hodisa Mayer (2001) multimediali o'qitish nazariyasi va Dunlosky va boshqalar (2013) tomonidan aniqlangan interaktiv o'rganish strategiyalarining samaradorligi bilan izohlash mumkin.

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MODELS OF CLOUD TECHNOLOGY INTEGRATION INTO ENTERPRISE MANAGEMENT

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Abstract: This article examines the main models, advantages, and practical aspects of integrating cloud technologies into enterprise management systems. The study analyzes IaaS, PaaS, and SaaS service models and describes the most effective ways to implement them in enterprise processes. Special attention is given to the economic benefits of cloud adoption, organizational readiness factors, and sector-specific recommendations for enterprises in Uzbekistan within the context of the "Digital Uzbekistan — 2030" strategy.

Keywords: cloud technologies, enterprise management, integration, IaaS, PaaS, SaaS, digital transformation, hybrid cloud, security, ERP, CRM, cost optimization.

1. Introduction

In the context of intensifying digital transformation processes in the modern economy, enterprises are leveraging advanced information technologies to make their management systems more efficient, flexible, and competitive. Cloud technologies represent one of the main directions of modern IT infrastructure, enabling enterprises to store and process large volumes of data and access them at any time from any location.

Major global companies — Amazon Web Services (AWS), Microsoft Azure, Google Cloud Platform, and Alibaba Cloud — provide cloud services, making this technology accessible to millions of enterprises worldwide. According to Gartner's 2023 forecast, global spending on cloud services exceeded \$600 billion, confirming the rapid pace of adoption across all sectors of the economy [1].

In the Republic of Uzbekistan, within the framework of the "Digital Uzbekistan — 2030" strategy, the implementation of cloud technologies in public and private enterprises is being carried out at an accelerated pace. The government has prioritized the digitalization of state services, logistics, education, and healthcare. In this regard, developing scientifically grounded models for integrating cloud technologies into enterprise management is a pressing and strategically significant issue.

The purpose of this article is to analyze the main service models of cloud technologies, examine effective methods for integrating them into enterprise management systems, and develop practical recommendations adapted to the conditions of Uzbekistani enterprises.

2. Main Models of Cloud Technologies

Cloud technologies are classified based on three main service models: IaaS (Infrastructure as a Service), PaaS (Platform as a Service), and SaaS (Software as a Service). Each model performs specific functions in enterprise management and offers distinct advantages depending on the scale and sector of the organization.

IaaS Model. The IaaS model enables enterprises to rent virtual servers, storage devices, and network resources. This model is particularly suitable for enterprises that work with large volumes of data, allowing them to obtain the required computing capacity without purchasing physical servers. For example, a manufacturing enterprise can deploy an ERP (Enterprise Resource Planning) system for quality control on an IaaS basis. In this case, the enterprise can reduce IT infrastructure management costs by 40–60% [1]. AWS EC2, Microsoft Azure Virtual Machines, and Google Compute Engine are among the most widely adopted IaaS solutions globally.

PaaS Model. The PaaS model provides software developers with ready-made programming environments and tools. By using this model, enterprises can develop their own management systems faster and at lower cost. A CRM (Customer Relationship Management) system built on PaaS significantly improves the efficiency of the sales department. Research shows that enterprises using the PaaS model reduce the development time of new software products by an average of 30–50% [2]. Moreover, PaaS eliminates the burden of maintaining underlying infrastructure, allowing development teams to focus entirely on delivering business value.

SaaS Model. The SaaS model is currently the most widespread type of cloud service, delivering ready-made software over the internet. Using SaaS solutions such as Microsoft 365, Google Workspace, Salesforce, and 1C:Cloud, enterprises can manage documents, prepare financial reports, and monitor employee performance. The SaaS model is especially convenient for small and medium-sized enterprises (SMEs), as it eliminates the need to form a dedicated IT department and enables subscription-based pricing that scales with organizational growth.

3. Models of Integration into Enterprise Management

Three main models are used for integrating cloud technologies into enterprise management: Public Cloud, Private Cloud, and Hybrid Cloud models. The selection of the appropriate model depends on the enterprise's size, regulatory requirements, budget, and data sensitivity.

Public Cloud Model is a cloud environment designed for general users. In this model, all resources are managed by the cloud provider and the enterprise only pays for the services it uses. The public cloud model is effective for the following management processes: human resource management, financial accounting, customer relations, and project management. This model is the optimal solution for small and medium-sized businesses, as the initial investment is minimal and the time-to-deploy is measured in hours rather than months.

Private Cloud Model is a cloud environment created exclusively for a single organization, which can be hosted within the enterprise or in a dedicated data center. This model is suitable for banks, insurance companies, and government institutions that work with confidential data. In a private cloud, the security and confidentiality of data are guaranteed while all modules of the management system are managed in an integrated manner [3]. Although capital expenditure for private cloud deployment is higher, the long-term return on investment is significant for data-sensitive industries.

Hybrid Cloud Model combines the advantages of both public and private cloud models. An enterprise can store critical and confidential data in a private cloud while using the public cloud for processes that require high computing power or rapid scalability. Research shows that 87% of large enterprises prefer the hybrid cloud model because it balances flexibility and security [4]. In Uzbekistan, this model is increasingly being adopted by commercial banks and large industrial enterprises.

4. Practical Results and Challenges of Integration

Implementing cloud technologies into enterprise management provides a number of important advantages. First, costs for maintaining IT infrastructure are reduced by 35–70%. Second, employees can access the corporate system from anywhere, regardless of their location, which is critical for enterprises with geographically distributed branches. Third, adding new services and scaling the system is accomplished with minimal effort and no downtime. Fourth, backup copies of data are stored automatically and recovery procedures are dramatically simplified.

According to a case study conducted at a medium-sized manufacturing enterprise in Samarkand Oblast, the migration from on-premises infrastructure to a hybrid cloud environment resulted in a 48% reduction in annual IT operating costs and a 62% improvement in system uptime over a 12-month period. Employee productivity increased by approximately 23% as teams gained access to real-time data and collaborative tools from remote locations [5].

However, a number of challenges also exist during the integration process. Ensuring data security and confidentiality is the primary challenge, as enterprises are obliged to trust the cloud provider's security policy. In addition, an internet outage can halt all management processes, making redundant connectivity a prerequisite for mission-critical deployments. Furthermore, migrating existing legacy systems to the cloud may require substantial technical effort and investment of time. Another significant challenge for enterprises in Uzbekistan is the shortage of qualified IT specialists. To effectively manage cloud technologies, enterprises need staff with expertise in Cloud Engineering, DevOps, and cybersecurity. In this regard, special attention should be paid to training personnel through cooperation between higher education institutions and professional IT training centers. The Ministry of Digital Technologies of Uzbekistan has begun implementing targeted programs in partnership with international technology vendors to address this skills gap.

5. Conclusion and Recommendations

Integrating cloud technologies into enterprise management is an important factor in enhancing the competitiveness of modern businesses and accelerating digital transformation. The results of the analysis show that different integration models should be applied depending on the size and sector of the enterprise. For small and medium-sized enterprises, the public cloud model based on SaaS is recommended, while for large and state-owned enterprises, the private or hybrid cloud model is advised to ensure compliance with data sovereignty regulations.

For successful integration, it is recommended to adhere to the following guidelines: develop a cloud strategy aligned with the enterprise's overall digital transformation plan; prioritize security requirements and regulatory compliance in all technical solutions; establish continuous training programs for employees on new technologies; and implement integration in stages, carefully evaluating the outcomes of each phase before proceeding. A phased approach reduces operational risk and allows organizations to build internal competencies progressively.

In conclusion, cloud technology integration is not merely a technological upgrade but a strategic transformation of how enterprises operate, compete, and deliver value. Enterprises in Uzbekistan that proactively adopt and effectively manage cloud solutions are positioned to achieve sustainable competitive advantage in the digital economy of the 21st century. Future research should focus on quantifying the long-term economic impact of cloud adoption across specific sectors such as agriculture, logistics, and public administration in the context of Central Asia's emerging digital landscape.

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ISLOM ME'MORCHILIGI NAQSHLARINI FRAKTAL GEOMETRIYA ASOSIDA MODELLASHTIRISH

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Annotatsiya: Islom me'morchiligi naqshlarining geometrik tuzilishi fraktal geometriya nuqtayi nazaridan tahlil qilinadi. Jumladan, naqsh elementlaridagi o'z-o'ziga o'xshashlik, takrorlanuvchanlik, simmetriya va cheksizlikka intilish kabi xususiyatlarning fraktal tabiat bilan bog'liqligi yoritiladi. Shuningdek, an'anaviy islomiy bezaklarning matematik asoslari ochib berilib, ularni kompyuter yordamida modellashtirish usullari ishlab chiqiladi. Naqshlarning geometrik tashkil topishi, transformatsiya jarayonlari, iteratsion qurilish tamoyillari hamda ularni algoritmik ifodalash masalalari ko'rib chiqiladi. Natijada islom me'morchiligi naqshlarini zamonaviy raqamli texnologiyalar asosida qayta yaratish va vizuallashtirish imkoniyatlari asoslab beriladi. Geometrik ornamentlarni matematik modellashtirishda fraktal geometriya muhim nazariy asoslardan biri hisoblanadi.

Fraktal geometriya murakkab va o'ziga o'xshash geometrik strukturalarni tavsiflash uchun ishlab chiqilgan matematik nazariya bo'lib, u ko'p bosqichli va iteratsion tuzilishga ega bo'lgan shakllarni modellashtirish imkonini beradi. Islom me'morchiligidagi ko'plab geometrik naqshlar ham ko'p darajali, o'ziga o'xshash elementlar kombinatsiyasidan tashkil topganligi sababli ularni fraktal geometriya yordamida tahlil qilish va modellashtirish mumkin.

Geometrik naqshlarning fraktal strukturasini tahlil qilish.

Islom me'morchiligidagi geometrik naqshlarning fraktal strukturasini an'anaviy tavsiflash yondashuvlaridan farqli ravishda matematik-modellashtirish asosida tizimli tahlil qilinadi. So'nggi yillarda geometrik ornamentlarni fraktal nuqtai nazardan o'rganishga qiziqish ortib bormoqda, chunki bunday naqshlar o'zida takrorlanuvchanlik, ierarxik tuzilish va o'ziga o'xshashlik kabi xususiyatlarni mujassam etadi.

Mazkur tadqiqotda geometrik naqshlarning fraktal strukturasini aniqlash uchun fraktal-geometrik dekompozitsiya modeli (FGDM) taklif etiladi. Ushbu modelga ko'ra, murakkab ornament quyidagi qatlamlardan iborat tizim sifatida qaraladi:

$$G = \{G_0, G_1, G_2\}$$

bu yerda G_0 - bazaviy geometrik karkas, G_1 - transformatsion qatlam, G_2 - fraktal detallashtirish qatlami.

Bunday yondashuv naqshni alohida elementlar yig'indisi sifatida emas, balki ko'p bosqichli fraktal tizim sifatida ko'rib chiqishga imkon beradi. Bu esa mavjud ishlardan farqli ravishda naqshlarning ichki strukturaviy qonuniyatlarini ochib berishga xizmat qiladi.

Fraktal strukturani aniqlash mezonlari.

Geometrik naqshlarning fraktal xususiyatlarini aniqlash uchun quyidagi mezonlar taklif etiladi.

O'ziga o'xshashlik (self-similarity);

Ierarxik tuzilish;

Iterativ qurilish;

Masshtab bo'yicha invariantlik.

Mazkur mezonlar Peitgen va Saupe tomonidan taklif etilgan fraktal xususiyatlar bilan mos keladi.

Fraktal o'xshashlik koeffitsienti (yangi mezon)

Ushbu ishda geometrik naqshlarning fraktallik darajasini baholash uchun yangi ko'rsatkich taklif etiladi.

$$K_f = \frac{N_s}{N_t}$$

bu yerda:

- N_s — o'ziga o'xshash modullar soni
- N_t — umumiy modullar soni

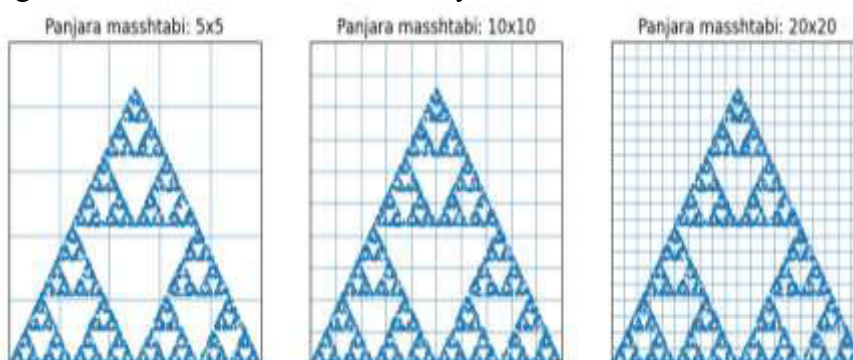
Mazkur ko'rsatkich orqali naqshlarning fraktal darajasi miqdoriy baholanadi.

Ko'p masshtabli fraktal tahlil.

Islom me'morchiligidagi naqshlar cheksiz emas, balki chegaralangan iteratsiyalar asosida quriladi. Shu sababli ushbu ishda samarali fraktal o'lchov tushunchasi kiritiladi.

$$D_{eff} = \frac{\log N(\varepsilon)}{\log(1/\varepsilon)}$$

Bu yerda $N(\varepsilon)$ — berilgan masshtabdagi faol elementlar soni. Ushbu yondashuv box-counting metodiga asoslangan bo'lib, fraktal o'lchovni amaliy sharoitda baholash imkonini beradi.



1-rasm. Box-counting asosida fraktal tahlil

Tahlil natijasida Islom me'morchiligidagi naqshlar quyidagi fraktal modellarga ajratiladi:

1.Radial fraktal struktura — yulduzsimon naqshlar

2.Modulli fraktal struktura — girih ornamentlari

3.Egri chiziqli fraktal struktura — arabesk naqshlar

Mazkur 2-rasmda fraktal-geometrik dekompozitsiya modelining matematik asoslari bosqichma bosqich ifodalangan. Model uch qatlamdan iborat bo'lib, har bir qatlam alohida matematik ifoda bilan tavsiflanadi.

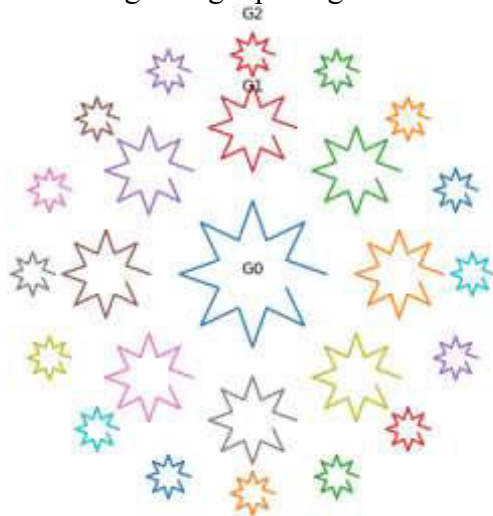
Islom me'morchiligidagi geometrik naqshlarni modellashtirish uchun klassik fraktal yondashuvlar bevosita ko'chirib olinmaydi, balki ularning imkoniyatlari tahlil qilinib, ornament tabiatiga moslashtirilgan yangi matematik modellar taklif etiladi. Mavjud adabiyotlar shuni ko'rsatadiki, IFS modellar o'ziga o'xshash va affine transformatsiyalar bilan hosil bo'ladigan strukturalar uchun juda qulay; L-tizimlar iterativ va qoidaviy o'sishni tavsiflaydi; R-funksiyalar esa murakkab sohalarni bitta analitik funksiya orqali ifodalash imkonini beradi. Biroq Islomiy naqshlarda ushbu uch yondashuv alohida holda yetarli emas: IFS modul joylashuvini beradi, L-tizim strukturaviy o'sishni beradi, R-funksiyalar esa aniq chegaraviy ifodani beradi. Shuning uchun ularni integratsiyalash zarur.

Uning atrofida joylashtirilgan kichik modullar esa shu shaklning masshtab bo'yicha kichraytirilgan nusxalaridan iborat bo'lib, ular geometrik jihatdan asosiy modulga o'xshashdir. Ushbu holat fraktal tizimlarning asosiy belgisi — turli masshtablarda bir xil yoki o'xshash strukturaning takrorlanishini ko'rsatadi.

2-rasmda ko'rsatilgan yo'nalishlar katta modul va kichik modullar o'rtasidagi strukturaviy bog'lanishni ifodalaydi. Bu esa geometrik naqshlarning fraktal xususiyatga ega ekanligini, ya'ni ularning ierarxik va o'z-o'zini takrorlovchi tuzilishga ega ekanligini tasdiqlaydi.

Fraktal geometriya murakkab va tartibsiz geometrik strukturalarni matematik jihatdan tavsiflash uchun ishlab chiqilgan zamonaviy matematik nazariya hisoblanadi. An'anaviy Evklid

geometriyasida asosiy e'tibor oddiy geometrik shakllar — chiziqlar, aylana, ko'pburchaklar va sirtlarga qaratilgan bo'lsa, fraktal geometriya o'ziga o'xshash, ko'p darajali va iteratsion strukturalarga ega bo'lgan shakllarni o'rganishga qaratilgan



2-rasm. Geometrik naqshning fraktal dekompozitsiya modeli

Xulosa qilib aytganda, geometrik naqshlarning fraktal strukturasini tahlil qilish uchun yangi fraktal-geometrik dekompozitsiya modeli, fraktal o'xshashlik koeffitsienti va ko'p masshtabli tahlil yondashuvi taklif etildi. Ushbu metodlar mavjud ilmiy ishlardan farqli ravishda naqshlarni faqat tavsiflash emas, balki ularni matematik modellashirish va miqdoriy baholash imkonini beradi.

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TASVIRLARNI QAYTA ISHLASHDA FREDGOLM INTEGRAL TENGLAMALARINING QO'LLANILISHI

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Annotatsiya. Ushbu tezisda tasvirlarni qayta ishlash usullari, raqamli tasvir turlari, tasvir sifatiga ta'sir qiluvchi omillar, tasvirlarni qayta ishlashda qo'llaniladigan filtrlar tahlili keltirib o'tilgan. Tasvirlarga ishlov berishda birinchi va ikkinchi tur Fredgolm integral tenglamalarini qo'llash haqida boshlang'ich tushunchalar berilgan.

Asosiy qisim

Tasvirni ikki o'lchovli $f(x,y)$ funksiya sifatida aniqlash mumkin, bunda x va y — fazodagi (tekislikdagi) koordinatalar hisoblanadi. Har bir (x,y) koordinata juftligi bilan aniqlanuvchi nuqtadagi f funksiyaning qiymati esa shu nuqtadagi tasvirning intensivligi deb ataladi. Agar x , y va f kattaliklari chekli sondagi diskret qiymatlarni qabul qilsa, bunday tasvir raqamli tasvir deyiladi.

Raqamli tasvirlar o'zining tuzilishi, spektral tarkibi va qo'llanish sohasiga qarab bir necha asosiy turlarga ajratiladi. Ular quyidagilar:

- Ikkilik tasvirlar eng sodda tasvir turlaridan biri bo'lib, har bir piksel faqat ikki xil qiymatdan birini qabul qiladi. Odatda ushbu qiymatlar qora va oq ranglarni ifodalaydi. Matematik ko'rinishi quyidagicha ifodalanadi:

$$f(x, y) \in \{0, 1\}$$

- Kulrang tasvirlar bir kanalli tasvirlar hisoblanib, ularda rang haqida ma'lumot mavjud bo'lmaydi. Har bir piksel faqat yorug'lik intensivligini ifodalaydi. Odatda 8-bitli kulrang tasvirlarda piksel qiymatlari 0 dan 255 gacha oraliqda bo'ladi:

$$0 \leq f(x, y) \leq 255$$

- Rangli tasvirlar bir nechta rang kanallaridan tashkil topgan bo'lib, eng keng tarqalgan modeli RGB modeli hisoblanadi. RGB modeli qizil, yashil va ko'k rang kanallaridan iborat:

$$I(x, y) = (R, G, B)$$

bu yerda R, G va B mos ravishda qizil, yashil va ko'k rang komponentalarini ifodalaydi.

- Ko'p spektrli (multispectral) tasvirlar RGB tasvirlarga nisbatan ko'proq spektral kanallarga ega bo'ladi. Ushbu tasvirlarda elektromagnit spektrning turli diapazonlarida olingan ma'lumotlar saqlanadi.

- Giperspektral tasvirlar juda ko'p va uzluksiz spektral diapazonlardan tashkil topadi. Bunday tasvirlarda har bir piksel uchun yuzlab spektral qiymatlar mavjud bo'lishi mumkin.

- Uch o'lchamli va hajmli tasvirlar fazodagi obyektlarning geometrik tuzilishini ifodalash imkonini beradi.

Tasvir yaratilayotganda texnik ayrim bir sabablar tufayli shovqinlar paydo bo'lishi mumkin. Tasvirdagi shovqinlar — bu tasvir sifati yomonlashishiga olib keluvchi tasodifiy buzilishlar hisoblanadi. Raqamli tasvirlarda shovqinlarni paydo bo'lishining asosiy manbalari tasvirga olish yoki yaratilish jarayoni hamda uni uzatish jarayoni hisoblanadi. Bunday shovqinlar tasvir sifatiga salbiy ta'sir ko'rsatadi va turli xil noaniqliklarga olib keladi. Misol uchun, tasvirdagi obyektlarni noaniqligi, ranglarni noto'g'ri akslanishi va h.k. Buning natijasida tasvirlarni qayta ishlash ya'ni shovqinlarni bartaraf etish ehtiyoji tug'iladi.

Raqamli tasvirlardagi mavjud bo'lgan shovqinlarni kamaytirish yoki bartaraf etish uchun filtrlardan foydalaniladi. Filtrlarni bir necha turlari mavjud. Ularni ikkita sinfga bo'lishimiz mumkin: fazoviy soha filtrlari va chastota sohasi filtrlari. Fazoviy soha filtrlariga o'rtacha qiymatli filtr, Gauss filtri, Viner filtri misol qilsak bo'ladi. Chastota sohasi filtrlariga esa Ideal past chastotali filtr, Gauss past chastotali filtri, Yuqori chastotali filtrlar misol bo'la oladi.

Raqamli tasvirlarga ishlov berishda ya'ni, filtratsiya, tasvirlarni tiklash, tasvirlarni aniqlashtirish, konvolutsiya uchun integral tenglamalar asosiy matematik operator hisoblanadi. Integral tenglama deb noma'lum funksiya integral ostida joylashgan tenglamaga aytiladi. Aynan matematik fizika, signal va tasvirlarga ishlov berish masalalarida keng qo'llaniladigan integral tenglama turlariga birinchi va ikkinchi tur Fredgolm integral tenglamalari misol bo'la oladi.

Birinchi tur Fredgolm integral tenglamasini umumiy ko'rinishi quyidagicha:

$$\int_a^b K(x, t)\varphi(t)dt = f(x)$$

Ikkinchi tur Fredgolm integral tenglamasini umumiy ko'rinishi quyidagicha:

$$\varphi(x) - \lambda \int_a^b K(x, y)\varphi(y)dy = f(x)$$

Bu yerda $\varphi(x)$ - noma'lum funksiya, $K(x, y)$ va $f(x)$ – oldindan berilgan funksiyalar, λ - tenglamaning parametri hisoblanadi.

Raqamli tasvirlarga ishlov berishda Fredgolm integral tenglamalari tasvirlarni tiklash, xiralashgan tasvirni aniqlashtirish, shovqinlarni kamaytirish, konvolutsiya modellarida foydalaniladi. Ayniqsa Gaus konvolutsion modeli(Gaus past chastotali filtri) Fredgolm integral tenglamasi bilan bog'liq hisoblanadi.

Gaus konvolutsiyasini raqamli tasvirlarga ishlov berishda qo'llash natijasida tasvir xiralashadi(bulur) va shovqin kamayadi. Bunda berilgan f tasvirga yadro G ni qo'llab, $g=G*f$

topiladi. Bu amal birinchi tur Fredgolm integral tenglamasini to'g'ri qo'llanilishi hisoblanadi. Xiralashgan tasvirdan tiniq tasvir hosil qilish uchun esa berilgan xiralashgan rasm g va yadro G dan f ni topish kerak bo'ladi. Bu amal dekonvolutsiya deb ham ataladi. Bu masala yomon shartlangan yoki nokorrekt masala hisoblanadi. Yuqoridagi masalani yechish uchun regularizatsiya usullari qo'llagan holda birinchi tur Fredgolm integral tenglamasi ikkinchi tur Fredgolm integral tenglamaga ya'ni korrekt masalaga keltiriladi hamda hisoblanadi. Natijada xiralashgan tasvirdan asl tasvirni qayta tiklash imkoniyati yaratiladi

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ТЕХНОЛОГИИ БЛОКЧЕЙН И ИХ ПРИМЕНЕНИЕ В ЮРИДИЧЕСКОЙ СФЕРЕ РЕСПУБЛИКИ УЗБЕКИСТАН: АНАЛИЗ НОРМАТИВНЫХ АКТОВ И ИНИЦИАТИВ Утепбергенова Г.Х.

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В условиях стремительного развития информационных технологий и цифровой экономики особую актуальность приобретают вопросы внедрения инновационных решений в различные сферы общественной жизни. Одной из наиболее перспективных технологий современности является технология блокчейн, которая представляет собой распределённую систему хранения данных, обеспечивающую высокий уровень прозрачности, безопасности и неизменности информации.

В последние годы Республика Узбекистан уделяет особое внимание развитию цифровой экономики и внедрению современных информационных технологий. Государством принимаются меры по формированию нормативно-правовой базы, регулирующей использование блокчейн-технологий и крипто активов. В частности, разрабатываются законодательные акты, направленные на регулирование деятельности крипто валютных бирж, создание благоприятных условий для развития финтех-индустрии и внедрение инновационных технологий в систему государственного управления.

Несмотря на активное развитие данной сферы, вопросы правового регулирования блокчейн-технологий остаются недостаточно изученными и требуют дальнейшего научного анализа. Особенно актуальным является исследование возможностей применения блокчейн-технологий в юридической практике, включая использование смарт-контрактов, цифровых реестров и автоматизацию юридических процедур.

СТРАТЕГИЯ «ЦИФРОВОЙ УЗБЕКИСТАН-2030»

В республике реализуются комплексные меры по активному развитию цифровой экономики, а также широкому внедрению современных информационно-коммуникационных технологий во все отрасли и сферы, прежде всего, в государственное управление, образование, здравоохранение и сельское хозяйство. Министерством цифровых технологий Республики Узбекистан при участии заинтересованных министерств и ведомств, представителей бизнес-сообщества и научных кругов, а также зарубежных экспертов разработана Стратегия «Цифровой Узбекистан — 2030».

За последние пять лет экспорт отрасли увеличился с 170 миллионов до почти 1 миллиарда долларов. Скорость интернета выросла в 7 раз, мобильного интернета — в 4,5 раза. В прошлом году стартапы привлекли 70 миллионов долларов венчурных инвестиций.

В результате Узбекистан поднялся на 12 позиций и вошел в топ-100 глобального рейтинга экосистем стартапов. Также страна поднялась на 17 позиций в международном Индексе

готовности к искусственному интеллекту, заняв первое место в Центральной Азии. Узбекистан возглавил рейтинг стран СНГ по темпам роста телекоммуникационной отрасли. Работа в этом направлении последовательно продолжается. В частности, на следующий год намечены следующие цели: цифровизация 70 процентов государственных услуг, увеличение объема IT-услуг до 100 триллионов сумов. Также планируется подняться как минимум на 55-е место в Индексе развития электронного правительства. Для достижения этих показателей разработаны проекты ряда документов. В регионах созданы центры государственных услуг для эффективного использования населением государственных услуг.

На сегодняшний день цифровизированы 760 видов государственных услуг, цифровыми сервисами воспользовались 10 миллионов граждан. В результате цифровизации отменено истребование от населения более 70 видов справок и документов.

Вместе с тем, в целях обеспечения населения и туристов, прибывающих в нашу страну, качественным, бесплатным интернетом в общественных местах, в частности, в государственных учреждениях, торговых центрах, на рынках, в аэропортах, на вокзалах и в ряде мест организованы бесплатные Wi-Fi зоны. За последние два года в нашей стране было открыто 215 учебных IT-центров. Объявлено о создании финансовых льгот таким учебным заведениям и их выпускникам. Оправдал себя и проект «Миллион программистов». В настоящее время большинство специалистов IT-парков — это молодые люди, окончившие данную программу. Обучение молодежи будет расширено, в том числе через платформу «Coursera». Самые талантливые, прошедшие отбор, будут обучены для международного IT-рынка на основе отдельной программы.

Нормативные акты и инициативы узбекистана в сфере блокчейна

Некоторые нормативные акты и инициативы Узбекистана в сфере блокчейна:

Постановление Президента Республики Узбекистан от 3 июля 2018 года №3832 «О мерах по развитию цифровой экономики в

Республике Узбекистан». Документ предусмотрел создание нормативно-правовой базы в сфере блокчейн-платформы. В частности, установил, что операции с крипто-активами не являются объектами налогообложения, а доходы по таким операциям не включаются в налогооблагаемую базу.

Постановление Президента Республики Узбекистан от 2 сентября 2018 года №3926 «О мерах по организации деятельности крипто-бирж в Республике Узбекистан».

Положение о порядке лицензирования деятельности провайдеров услуг в сфере оборота крипто-активов (рег. №3380 от 15 августа 2022 года), утвержденное приказом директора Национального агентства перспективных проектов Республики Узбекистан от 14 июля 2022 года №32. Положение об установлении размеров сборов за осуществление деятельности в сфере оборота крипто-активов, порядке их уплаты и распределения (рег. №3388 от 28 сентября 2022 года).

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ARDUINO PLATFORMASINING ARXITEKTURASI VA TEXNIK XUSUSIYATLARI

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Annotatsiya. Mazkur maqolada Arduino platformasining arxitekturasini va texnik xususiyatlari ilmiy-nazariy jihatdan batafsil tahlil qilinadi. Maqolada platformaning modulli tuzilishi, energiya samaradorligi, moslashuvchanligi va tezkor prototiplash imkoniyatlari yoritib berilgan. Bundan tashqari, Arduino platformasining STEM ta'limidagi o'rni, amaliy loyihalarni ishlab chiqishdagi ahamiyati hamda robototexnika, aqlli uy tizimlari va IoT texnologiyalaridagi qo'llanilish sohalari ko'rib chiqildi.

Kalit so'zlar. Arduino, mikrokontroller, ATmega328P, o'rnatilgan tizimlar, apparat arxitekturasini, dasturlash, STEM ta'lim

Kirish

Hozirgi kunda axborot texnologiyalari, avtomatlashtirish tizimlari va raqamli qurilmalar jadal sur'atlarda rivojlanib bormoqda. Zamonaviy texnologik jarayonlarda mikrokontroller platformalari muhim o'rin egallab, ular turli elektron tizimlarni boshqarish, ma'lumotlarni qayta ishlash hamda avtomatik qurilmalarni yaratishda keng qo'llanilmoqda. Ayniqsa, robototexnika, Internet of Things (IoT), aqlli uy tizimlari, sanoat avtomatlashtirish va ta'lim sohalari mikrokontroller texnologiyalarining ahamiyati tobora ortib bormoqda. Shu sababli ushbu texnologiyalarni o'rganish va amaliyotga tatbiq etish bugungi kunning dolzarb masalalaridan biri hisoblanadi. Mikrokontroller platformalari orasida Arduino o'zining soddaligi, ochiq kodli arxitekturasini va keng imkoniyatlari bilan ajralib turadi. Arduino platformasi ilk bor 2005-yilda Italiyada yaratilgan bo'lib, dastlab elektronika va dasturlashni o'rganishni osonlashtirish maqsadida ishlab chiqilgan. Keyinchalik platforma o'zining moslashuvchanligi, arzonligi va foydalanish qulayligi sababli nafaqat ta'lim tizimida, balki ilmiy tadqiqotlar, sanoat va muhandislik loyihalarida ham keng qo'llanila boshlandi. Bugungi kunda Arduino platformasi dunyo bo'ylab millionlab foydalanuvchilar tomonidan robotlar, aqlli qurilmalar, monitoring tizimlari va avtomatlashtirilgan boshqaruv tizimlarini yaratishda samarali vosita sifatida ishlatilmoqda.

Arduino platformasi nafaqat texnik jihatdan, balki metodologik nuqtai nazardan ham muhim ahamiyat kasb etadi. Xususan, STEM ta'lim konsepsiyasini amalga oshirishda Arduino platformasi nazariy bilimlarni amaliy ko'nikmalar bilan uyg'unlashtirish imkonini beradi. Talabalar va o'quvchilar Arduino yordamida turli elektron qurilmalarni yaratish jarayonida dasturlash, elektronika, algoritmik fikrlash va muammolarni hal etish ko'nikmalarini rivojlantiradilar. Shu sababli platforma zamonaviy ta'lim tizimida innovatsion pedagogik vosita sifatida keng qo'llanilmoqda [1, 2].

Asosiy qism

Arduino platformasi zamonaviy o'rnatilgan tizimlar (embedded systems) texnologiyasiga asoslangan ochiq kodli mikrokontroller platformasi hisoblanadi. Ushbu platforma elektron qurilmalarni boshqarish, ma'lumotlarni qayta ishlash va avtomatlashtirilgan tizimlarni yaratishda keng qo'llaniladi. Arduino platformasining asosiy afzalligi uning soddaxitekturasini, foydalanish qulayligi va turli qurilmalar bilan integratsiya qilish imkoniyatiga ega ekanligidir. Platforma apparat va dasturiy ta'minotning uyg'unlashgan tizimi sifatida ishlaydi [3, 4].

Arduino tizimi klassik "Input-Process-Output" (IPO) modeliga asoslanadi. Ushbu model quyidagi bosqichlardan iborat:

Birinchi bosqich — Kirish (Input). Bu jarayonda sensorlar yoki tashqi qurilmalar orqali ma'lumotlar qabul qilinadi. Masalan, harorat sensori, yorug'lik sensori yoki harakat sensori tashqi muhitdagi o'zgarishlarni aniqlaydi va signal hosil qiladi.

Ikkinchi bosqich — Qayta ishlash (Processing). Ushbu bosqichda mikrokontroller kiruvchi ma'lumotlarni dastur asosida tahlil qiladi. Arduino platformasidagi ATmega328P mikrokontrolleri barcha hisoblash va boshqaruv jarayonlarini bajaradi. Mikrokontroller ma'lumotlarni algoritm asosida qayta ishlab, keyingi harakatni belgilaydi.

Uchinchi bosqich — Chiqish (Output). Tahlil qilingan ma'lumotlarga asoslanib, tizim turli aktuatorlar yoki qurilmalarni boshqaradi. Masalan, LED lampalarni yoqish, motorni harakatlantirish yoki displeyga ma'lumot chiqarish kabi amallar bajariladi [5, 6].

Arduino platformasining apparat arxitekturasini modulli tuzilishga ega. Bu esa foydalanuvchilarga turli modullar va qo'shimcha qurilmalarni ulash imkonini beradi. Eng mashhur modellardan biri Arduino Uno hisoblanadi. Ushbu plata ATmega328P mikrokontrolleriga asoslangan bo'lib, sodda va o'rta darajadagi loyihalarni amalga oshirish uchun keng qo'llaniladi. Arduino Uno platasining asosiy tarkibiy qismlari quyidagilardan iborat:

- Mikrokontroller
- Raqamli kirish va chiqish portlari
- Analog kirish portlari
- USB interfeysi
- Quvvat boshqaruv tizimi
- Takt generatori
- Xotira modullari

Arduino Uno platasida 14 ta raqamli kirish/chiqish pinlari mavjud bo'lib, ular orqali sensorlar va boshqa qurilmalar ulanadi. Shuningdek, plata 6 ta analog kirish portiga ega. Ushbu portlar analog signallarni qabul qilib, ularni raqamli ko'rinishga o'tkazadi. Bu esa harorat, bosim yoki yorug'lik kabi fizik kattaliklarni o'lchash imkonini beradi. Arduino platformasining texnik xususiyatlari uning samaradorligini belgilaydi [6]. Arduino Uno 16 MHz takt chastotasida ishlaydi. Ushbu chastota mikrokontrollerning ma'lumotlarni qayta ishlash tezligini ta'minlaydi. Platforma 32 KB flash xotiraga ega bo'lib, unda foydalanuvchi dasturlari saqlanadi. Bundan tashqari, 2 KB operativ xotira (RAM) va 1 KB EEPROM xotira mavjud. Arduino platformasining muhim jihatlardan biri uning dasturiy muhitidir. Arduino IDE dasturiy muhiti foydalanuvchilarga C/C++ dasturlash tilida dastur yozish imkonini beradi. Ushbu muhit sodda interfeysga ega bo'lib, yangi boshlovchilar uchun ham qulay hisoblanadi. Arduino dasturlari "sketch" deb ataladi va ular asosan ikki funksiyadan iborat:

```
void setup() {  
}  
void loop() {  
}
```

setup() funksiyasi dastur ishga tushganda bir marta bajariladi va boshlang'ich sozlamalarni amalga oshiradi. loop() funksiyasi esa cheksiz sikl asosida ishlaydi va qurilmaning asosiy funksiyalarini boshqaradi.

Shu bilan birga, platformaning ayrim cheklavlari ham mavjud. Xususan, yuqori aniqlikdagi va murakkab hisoblashlarni talab qiladigan tizimlarda Arduino'ning texnik imkoniyatlari cheklangan bo'lishi mumkin. Operativ xotira hajmining kichikligi va hisoblash quvvatining pastligi katta hajmdagi ma'lumotlarni qayta ishlashda muammolar keltirib chiqaradi. Shunga qaramasdan, Arduino platformasi sodda va o'rta darajadagi loyihalarni amalga oshirish uchun samarali va qulay texnologik vosita hisoblanadi.

Arduino platformasining texnik xususiyatlari

Arduino platformasining texnik xususiyatlari uning funksional imkoniyatlarini belgilovchi asosiy omillardan biri hisoblanadi. Ushbu platforma mikrokontroller asosida ishlovchi elektron qurilmalarni boshqarish, sensorlardan ma'lumot olish va turli avtomatlashtirilgan tizimlarni yaratish imkonini beradi. Arduino oilasiga turli modellar kiradi, biroq ular orasida eng keng tarqalgan va ommabop model Arduino Uno hisoblanadi. Ushbu plata ATmega328P mikrokontrolleriga asoslangan bo'lib, sodda va o'rta darajadagi loyihalarni amalga oshirish uchun mo'ljallangan.

Arduino Uno platasining markaziy qismi ATmega328P mikrokontrolleri hisoblanadi. Ushbu mikrokontroller barcha hisoblash va boshqaruv jarayonlarini amalga oshiradi. Mikrokontroller foydalanuvchi tomonidan yozilgan dastur kodlarini bajaradi hamda tashqi qurilmalar bilan ma'lumot almashishni ta'minlaydi. Arduino platformasining muhim texnik xususiyatlaridan biri uning raqamli va analog portlarga ega ekanligidir. 14 ta raqamli pinlar orqali LED lampalar, relelar, motorlar va boshqa raqamli qurilmalarni boshqarish mumkin. Shuningdek, 6 ta analog kirish portlari yordamida harorat, yorug'lik, bosim va namlik sensorlaridan ma'lumot olish imkoniyati mavjud.

Platformadagi PWM (Pulse Width Modulation) pinlari analog signalga yaqin boshqaruv imkoniyatini yaratadi. Ushbu pinlar yordamida motor tezligini boshqarish yoki LED yorqinligini sozlash mumkin. Arduino Uno 16 MHz takt chastotasida ishlaydi. Bu mikrokontrollerning ma'lumotlarni qayta ishlash tezligini belgilaydi. Shuningdek, 32 KB flesh xotira foydalanuvchi dasturlarini saqlash uchun xizmat qiladi. 2 KB SRAM esa dastur ishlashi davomida vaqtinchalik ma'lumotlarni saqlaydi. EEPROM xotira esa elektr toki uzilganda ham ma'lumotlarni saqlab qolish imkonini beradi. Arduino platformasi USB interfeysi orqali kompyuter bilan bog'lanadi. Ushbu interfeys orqali dastur yuklanadi va qurilma quvvat bilan ta'minlanadi. Platforma tashqi quvvat manbai orqali ham ishlashi mumkin, bu esa portativ qurilmalarni yaratishda muhim ahamiyatga ega.

Xulosa

Tadqiqot natijalariga ko'ra, Arduino platformasi zamonaviy elektronika va o'rnatilgan tizimlarni yaratishda muhim texnologik vosita hisoblanadi. Arduino platformasi zamonaviy raqamli texnologiyalarni o'rganish va innovatsion elektron qurilmalarni yaratishda samarali vosita bo'lib, kelajakda sun'iy intellekt va IoT texnologiyalari bilan integratsiyalashuvi uning qo'llanilish doirasini yanada kengaytirishi kutilmoqda.

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RAQAMLI TEXNOLOGIYALAR ASOSIDA MASOFAVIY TA'LIMNI RIVOJLANTIRISH ISTIQBOLLARI

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Annotatsiya. Maqolada masofaviy ta'limning normativ huquqiy asoslari, uning raqamli texnologiyalarni rivojlanishdagi o'рни, O'zbekiston ta'lim tizimidagi ahamiyati hamda axborot texnologiyalari sohasidagi ta'siri ilmiy jihatdan tahlil qilinadi. Shuningdek, zamonaviy platformalar, Learning Management System(LMS) tizimlari hamda mobil ta'lim vositalarining masofaviy ta'limdagi roli o'rganilgan. O'zbekistonda masofaviy ta'limning joriy etilishi, mavjud muammolar va istiqboldagi rivojlanish yo'nalishlari tahliliy yondashuv asosida bayon qilingan.

Kali so'zlar: masofaviy talim, raqamli texnologiyalar, LMS, Moodle, Zoom, bulutli texnologiyalar, IT-ta'lim, raqamlashtirish

Bizga ma'lumki, oxirgi yillarda jahonda ro'y berayotgan so'nggi o'zgarishlar ta'limni yuqori bosqichga olib chiqish masalasini ko'ndalang qo'ymoqda. O'zbekiston oliy ta'lim muassasalarida masofaviy ta'lim shaklini joriy etish axborot-kommunikatsiya texnologiyalari imkoniyatlaridan sohada samarali foydalanishni taqozo etmoqda. 2022 yil 3 oktabrda O'zbekiston Respublikasi Vazirlar mahkamasining "Oliy ta'lim tashkilotlarida masofaviy ta'lim shaklini joriy etish chora-tadbirlari to'g'risida"gi 559-sonli qarori masofaviy o'qitish tizimining normativ huquqiy hujjati sifatida tan olinmoqda. Ushbu qarorning ilova qismida "Oliy ta'lim tashkilotlarida masofaviy ta'limni tashkil etish tartibi to'g'risida nizom" keltirilgan. Nizom 7 bob, 33 banddan tashkil topgan bo'lib, O'zbekiston oliy ta'lim tashkilotlarida masofaviy ta'lim tizimini huquqiy asosini qamrab oladi.

Masofaviy ta'lim to'g'risidagi nizomda quyidagi asosiy tushunchalar keltirilgan[2]:

masofaviy ta'lim — talaba va ta'lim beruvchining axborot-kommunikatsiya texnologiyalaridan foydalanishiga, interaktiv audio va videokonferensiyalar orqali ma'lum vaqt orasida o'zaro muloqotda bo'lishiga, elektron pochta orqali to'g'ri va teskari aloqa o'rnatishiga, jumladan

xabarlarni yuborishi va qabul qilishiga mo'ljallangan, bilim va ko'nikmalarni, o'quv dasturlarini masofadan turib o'zlashtirishga yo'naltirilgan ta'lim shakli;

masofaviy ta'limni boshqarish tizimi — ta'lim jarayonini rejalashtirish, boshqarish, amalga oshirish va baholashda qo'llaniladigan dasturiy mahsulot (elektron ta'lim platformasi);

masofaviy ta'lim jarayonining ishtirokchilari — ta'lim tashkilotining masofaviy ta'lim shakliga qabul qilingan talabalar, professor-o'qituvchilar hamda masofaviy ta'limning tashkiliy-texnik va metodik ta'minotini amalga oshirishga mas'ul shaxslar;

masofaviy ta'lim texnologiyasi — talabalarga o'quv materiallarining asosiy hajmini yetkazishni, talaba va professor-o'qituvchining o'zaro interfaol harakatini ta'minlab beruvchi, o'quv materialini o'zlashtirish bo'yicha mustaqil ishlashi uchun talabaga imkoniyat taqdim etuvchi axborot-kommunikatsiya va o'qitish texnologiyalari;

sinxron rejim — o'quv jarayoni ishtirokchilarining Internet jahon axborot tarmog'ida real vaqtdagi o'zaro aloqa rejimi;

o'quv kontenti — o'quv jarayonida talabalarining foydalanishi uchun mo'ljallangan, masofaviy ta'limni boshqarish axborot tizimiga joylashtirilgan o'quv metodik materiallar (o'quv rejalari, o'quv dasturlari, ma'ruza matnlari, videodarslar, taqdimotlar, topshiriqlar, imtihon materiallari, o'quv adabiyotlari).

2019 yil fevral oyida Qarshi davlat universiteti mutaxassisleri tomonidan jahon bankining AIF fondi asosida "O'zbekiston oliy ta'lim muassasalarida ta'lim jarayonini tashkil etishda yangi texnologiyalar" loyihasi o'z faoliyatini boshladi. Loyihaning asosiy maqsadi – talabalarni modul-kredit tizimi asosida o'qitish uchun eng muhim qismi talabalarining mustaqil ta'limiga e'tiborning qaratilganligi bo'ldi. Loyihaning bir qismi sifatida talabalarining mustaqil ta'lim olishi samaradorligini oshirishga qaratildi va mustaqil ta'limni to'liq bajarish mexanizmi shakllantirildi[3,4]. Loyihani bajarish jarayonida amaliy matematika, kimyo, filologiya va tillarni o'qitish: ingliz tili ta'lim yo'nalishlarining 1-kurslari tanlab olindi. Ushbu yo'nalishlarning barcha fanlari LMS platformasi orqali ro'yxatdan o'tkazildi va talabalarga platformada elektron resurslar bilan ta'minlandi. Loyihaning asosiy maqsadi talabalar bilimining baholashning shaffoflikka asoslangan texnologiyasini qo'llash, mustaqil ta'limga asoslangan masofaviy ta'lim uchun dastlabki shart-sharoitlar yaratishdan iborat[3,4]:

Loyihada ekspert OTMLar sifatida Buxoro davlat universiteti hamda Belgorod milliy tadqiqotlar universitetlari (Rossiya Federatsiyasi) professor-o'qituvchilari ishtirok etdilar. Loyiha ijrochilari tomonidan Rossiya Federatsiyasining Belgorod milliy tadqiqotlar universitetining "Pegas" masofaviy ta'lim tizimi chuqur o'rganilib, tahlil qilindi. <https://pegas.bsu.edu.ru> LMS kontentdagi ma'lumotlar, shuningdek ma'ruzalar, amaliy va laboratoriya mashg'ulotlari, videomateriallar, glossariylar, testlar va ularning har xil shakllari va adabiyotlar o'rganildi. Yuqoridagilarga asos qilib universitetning masofaviy ta'lim platformasi yaratildi. Platforma hozirgi paytda <https://moodle.qarshidu.uz> manzilida, sirtqi ta'lim shaklida esa <https://sirtqi.qarshidu.uz> manzilida faoliyat yuritmoqda. Platformada ma'ruza, topshiriq, test, seminar, glossariy, forum, chat, ma'lumotlar bazasi, kitob, gipermurojaat, papka, fayl, sahifa kabi elementlar shakllantirib borildi[4].

Dunyoda COVID-19 pandemiyasi masofaviy ta'limni rivojlanish uchun to'liq asos bo'ldi, deyishimiz mumkin. Loyiha doirasida 3 ta yo'nalishga 30 ga yaqin kurslar tashkil etilgan bo'lsa, o'rganilgan tajribalar asosida pandemiya paytida 1830 ta kurslar yaratildi. Quyidagi 1-jadvalda kurslarning fakultetlar kesimida taqdim etiladi[3]:

3-inchi

Fakultetlar	Jami kurslar	Kutubxona ta'lim	Sana ta'lim
Fizika-matematika	209	129	80
Tabiiy fanlar	202	158	44
Ijtimoiy fanlar	292	226	66
Xorijiy tillar	357	357	0
Filologiya	155	120	35
San'atshunoslik	208	162	46
Pedagogika	243	138	105
Ismoniy madaniyat	71	45	26
Magistratura bo'limi	93	93	0
Maxsus kurslar	402	0	402
JAMI	1830	1418	402

Xulosa qiladigan bo'lsak, maqolada O'zbekiston Respublikasi oliy ta'lim tizimida masofaviy ta'limning normativ huquqiy asoslari yaratilganligi va uning afzalliklari keltirib o'tilgan. Shuningdek, Qarshi davlat universitetida masofaviy ta'limni rivojlantirish uchun dastlabki shart-sharoitlar yaratilganligi hamda shaffoflikka asoslangan texnologiyani joriy qilinganligi ta'kidlab o'tilgan.

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SOLVING THE ISSUE OF ENERGY AND RESOURCE CONSERVATION IN DART USING FUNCTIONS

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Annotation: This article highlights solving the problem of energy and resource conservation using functions in the Dart programming language, while discussing functions, as well as parameterized and parameterless functions. Today, Dart is considered one of the most widely used programming languages. Using the Dart programming language, we can develop mobile applications, websites, and web apps.

Keywords: Dart programming language, Functions, Parameterized functions, Parameterless functions, Energy conservation, Resource saving, Smart home systems, Mobile application development.

In the modern era of rapid technological advancement, global challenges such as energy crises and resource depletion have become critical issues that require immediate, innovative solutions. As urbanization expands and the reliance on digital infrastructure grows, the demand for electricity continues to surge exponentially. To mitigate this pressure on power grids and reduce environmental impact, the integration of automation and smart management systems has shifted from a luxury to a necessity.

Modern software engineering plays a pivotal role in this transition, enabling developers to design intelligent systems capable of monitoring, regulating, and optimizing resource consumption in real-

time. Among the contemporary tools available to developers, the Dart programming language has emerged as one of the most powerful and widely adopted languages in the industry today. Backed by Google, Dart is primarily recognized for its versatility in building high-performance, cross-platform mobile applications, responsive websites, and robust web apps. Its clean syntax, strong typing, and modern features make it an ideal choice for writing scalable code that can handle complex logic, such as the data processing required for smart home systems and eco-friendly automation tools. At the core of any efficient software architecture lies the effective use of functions. In Dart, functions are first-class citizens, meaning they act as the foundational building blocks for structural logic and code reusability.

This article explores how to address the global issue of energy and resource conservation using Dart's diverse functional capabilities. It provides an in-depth analysis of structural concepts, focusing on the distinct roles and implementation strategies of both parameterized and parameterless functions. By mapping these programming concepts directly onto real-world energy-saving scenarios, this study demonstrates how clean and strategic code design can drive meaningful solutions for global sustainability.

Dart is a true object-oriented language, so even functions are objects and have a type, `Function`. This means that functions can be assigned to variables or passed as arguments to other functions. You can also call an instance of a Dart class as if it were a function.

```
bool isNoble(int atomicNumber) {  
    return _nobleGases[atomicNumber] != null;  
}
```

Only *expressions* can appear between the arrow (`=>`) and the semicolon (`;`).

Expressions evaluate to values. This means that you can't write a statement where Dart expects a value. For example, you could use a conditional expression but not an if statement.

In the previous example, `_nobleGases[atomicNumber] != null;` returns a boolean value. The function then returns a boolean value that indicates whether the `atomicNumber` falls into the noble gas range.

A function can have any number of *required positional* parameters. These can be followed either by *named* parameters or by *optional positional* parameters (but not both).

Named parameters are optional unless they're explicitly marked as required. When defining a function, use `{param1, param2, ...}` to specify named parameters. If you don't provide a default value or mark a named parameter as required, their types must be nullable as their default value will be null:

This basic function monitors how long a light has been left on. It does not return any value (void) and triggers a warning if the duration exceeds a set limit.

```
void checkLightStatus(int hoursOn) {  
    if (hoursOn > 5) {  
        print("Warning: The light has been on for $hoursOn hours! Please turn it off.");  
    } else {  
        print("Energy consumption is within the normal range.");  
    }  
}
```

This function accepts the power rating of an appliance in watts and its operation time in hours. It calculates and returns the total energy consumed in kilowatt-hours (kWh).

```
double calculateEnergyUsage(double powerInWatts, double hours) {  
    return (powerInWatts * hours) / 1000; // Converts Watts to kWh  
}
```

Utility companies often implement tiered or standard pricing. If a specific promotional or night tariff is not provided, the function automatically applies the default rate using optional positional parameters (`[]`).

```
double calculateCost(double kwh, [double tariffRate = 450.0]) {
```

```

    return kwh * tariffRate;
}

```

In large-scale applications, using named parameters ({}) prevents arguments from being passed in the wrong order. This approach significantly enhances code readability and system safety.

```

void sendSmartAlert({required String roomName, required double totalCost, bool
isEmergencyShutdown = false}) {
    print("--- REPORT: $roomName ---");
    print("Total Cost: \${totalCost.toStringAsFixed(2)}");
    if (isEmergencyShutdown) {
        print("ALERT: The system has automatically turned off the appliances in this room!");
    }
}

```

When a function contains only a single expression, it can be shortened using the arrow syntax (=>). This is ideal for quick conditional checks, such as activating an eco-mode.

```

bool isEcoModeActive(double batteryLevel) => batteryLevel < 20;

```

In conclusion, addressing modern global energy and resource conservation challenges heavily relies on the development of smart and automated software solutions. This article has demonstrated that the Dart programming language offers exceptional, flexible, and robust capabilities to solve these pressing ecological issues. By building an energy-saving ecosystem through the strategic implementation of Dart functions—ranging from simple parameterless structures to complex parameterized blocks with named and optional constraints—developers can write highly efficient, clean, and reusable source code. Utilizing Dart's functional programming paradigm not only simplifies the calculation of power consumption and automation of utility controls but also optimizes overall system logic. As Dart continues to be a dominant framework for creating scalable cross-platform mobile and web applications, leveraging its modern syntax to implement function-based resource management models serves as a vital bridge between advanced software engineering and global environmental sustainability.

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GIS AND REMOTE SENSING FOR INTEGRATED ENVIRONMENTAL MONITORING OF THE ARAL SEA BASIN

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Abstract: This paper presents results of the author's ongoing research on the application of GIS and remote sensing technologies for integrated environmental monitoring of the Aral Sea basin. The study synthesises findings from a series of original investigations covering climate–land cover interactions, drought-induced forest degradation, and satellite-based spatial analysis of desertification dynamics. The results reveal accelerating desertification trends, measurable climate

feedbacks from the shrinking water body, and quantifiable forest cover loss driven by drought — findings with direct implications for regional environmental policy and digital monitoring systems in Uzbekistan.

The progressive desiccation of the Aral Sea constitutes one of the most thoroughly documented environmental catastrophes of the modern era. By 2023, the water surface had contracted to just 7.83% of its 1960 extent, a reduction driven primarily by Soviet-era irrigation diversions from the Amu Darya and Syr Darya rivers [4]. The consequences — desertification of the exposed seabed, regional climate disruption, soil salinisation, and collapse of local ecosystems — are spatially complex and evolve continuously, demanding monitoring tools capable of capturing change across large areas and long time spans. Our research programme, conducted over three years in the Aral Sea basin, has employed GIS and remote sensing as the primary methodological framework to address this challenge. This paper presents the integrated findings of that work and situates them within the broader context of digital environmental monitoring methodology.

Our analytical framework integrates three categories of satellite and spatial data. First, GRACE (Gravity Recovery and Climate Experiment) gravimetric satellite data provided time-series records of total water storage anomalies across the basin for the period 2002–2017, enabling quantification of water mass changes that surface imagery alone cannot capture [1]. Second, multi-temporal Landsat (5, 7, 8) and MODIS imagery formed the basis of land cover classification and change detection, processed using supervised classification algorithms calibrated against ground-truth observations collected during field campaigns in the Karakalpakstan region. Third, standardised drought indices — the Standardised Precipitation Index (SPI) and the Normalised Difference Vegetation Index (NDVI) derived from MODIS time series — were used to characterise drought intensity and its spatial footprint across the basin [3].

This multi-source approach addresses a recognised limitation in single-dataset studies: no individual satellite product captures the full complexity of the Aral Sea system. Gravimetric data reveals subsurface and groundwater dynamics invisible to optical sensors; radar-derived surface roughness indices detect salt crust formation and wind erosion risk; vegetation indices track biological responses to climatic stress with higher sensitivity than categorical land cover maps [5]. The integration of these layers within a GIS environment allows spatial cross-analysis — for instance, identifying zones where drought stress, land cover degradation, and proximity to the former shoreline co-occur, which we found to be the areas of highest ecological vulnerability.

Our analysis of GRACE data and climate records for 2002–2017 identified a statistically significant relationship between the rate of Aral Sea contraction and anomalies in regional surface air temperature, with the most pronounced warming signal observed in the 150–300 km zone downwind of the former southern shoreline [1]. This finding is consistent with the loss of the lake's thermal buffering capacity and confirms that the sea's retreat is not merely a hydrological event but a driver of measurable regional climate change. Seasonal analysis further revealed an increase in the frequency of extreme temperature events — both summer heat episodes and late-spring frosts — that directly affects agricultural viability in the Amu Darya delta.

Land cover analysis across the broader basin documented an 18.4% net reduction in vegetated area between 2000 and 2022, with the most rapid losses concentrated in the exposed Aralkum desert and the lower Amu Darya floodplain [2]. Importantly, our GIS-based spatial modelling allowed us to disaggregate this signal: approximately 60% of vegetation loss was attributable to increased aridity and drought stress, while the remaining 40% reflected direct anthropogenic land use change, primarily agricultural expansion and groundwater extraction. This disaggregation — which would be impossible without the spatial analytical capabilities of GIS — is critical for designing targeted policy responses, as the two drivers require fundamentally different mitigation strategies.

The drought-forest cover analysis produced the most spatially precise findings of the research programme [3]. By correlating NDVI-derived vegetation loss with SPI-based drought severity maps at 30-metre spatial resolution, we identified that forest cover within 200 km of the former shoreline declined by 23.7% over the study period, compared to 8.1% in control zones at greater distances. Crucially, this differential — 2.9 times higher loss rate in the near-shoreline zone — provides the

first quantitative spatial estimate of the Aral Sea's direct influence on upland forest degradation, a relationship previously hypothesised but not empirically bounded.

A central contribution of this research is the development of a reproducible GIS workflow for integrated basin-scale environmental monitoring that is applicable beyond the Aral Sea context. All primary data sources used — GRACE, Landsat, Sentinel-2, MODIS — are freely accessible through NASA and ESA open-data portals. Processing was conducted using open-source platforms (QGIS, Google Earth Engine) and standard spectral indices, ensuring that the methodology can be replicated by researchers across Central Asia without proprietary software licences. The growing availability of cloud-based GIS processing, combined with the expanding archives of high-resolution satellite imagery, means that the temporal and spatial resolution of this type of monitoring will continue to improve — a significant advantage for a region where ground-based observation networks remain sparse [5].

The integrated application of GIS and remote sensing technologies has enabled our research team to generate a spatially detailed, multi-dimensional picture of environmental change in the Aral Sea basin that no single data source or conventional methodology could produce. The key quantitative findings — a 2002–2017 climate warming signal attributable to lake contraction, an 18.4% net vegetation loss across the basin, and a 23.7% forest cover decline in the near-shoreline zone — provide an empirical foundation for evidence-based environmental management in the region. As Uzbekistan advances its national digitalisation agenda, geospatial monitoring of this kind represents both a scientific priority and a practical demonstration of how modern digital technologies can be mobilised to address the country's most pressing environmental challenges.

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MODERN METHODS AND IMPORTANCE OF PROTECTION IN E-HEALTH SOFTWARE

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Abstract — Medical software connected to imaging devices like ultrasound machines works with patient data that, if leaked or tampered with, can lead to serious clinical harm. In this paper, we look at the key security protocols that such systems actually need — things like TLS 1.3, OAuth 2.0, HL7 FHIR, AES-256 encryption, differential privacy, and proper audit logging. We also put forward a layered protection model based on real deployment experience. The main takeaway is straightforward: relying on a single security measure is not enough, and it never really was.

Keywords — *e-health security, cybersecurity, TLS 1.3, OAuth 2.0, HL7 FHIR, HIPAA, differential privacy, medical data protection*

1. INTRODUCTION

Healthcare software has changed enormously over the past decade. Systems that once ran on isolated hospital networks now connect directly to diagnostic hardware, cloud storage, and external APIs. Ultrasound machines, for example, no longer just produce images — they feed data into software pipelines that classify findings, flag abnormalities, and write results back into patient records. This is genuinely useful, but it also opens up attack surfaces that did not exist before.

2. WHAT ACTUALLY THREATENS E-HEALTH SOFTWARE

Ransomware has become the dominant threat to hospital IT in recent years, and medical software is a natural entry point precisely because it sits at the boundary between clinical hardware and the hospital network. A less discussed but equally serious risk is re-identification: even after anonymization, exported datasets often carry enough quasi-identifiers — age group, region, diagnosis code — that individuals can be traced back. Ultrasound images in particular carry DICOM metadata that directly identifies patients if not explicitly removed. Finally, software integrity attacks — where a malicious update or a compromised dependency quietly alters diagnostic logic — are specific to medical software and almost never caught without dedicated integrity checking.

Together these threats map onto four properties that any serious e-health security posture must deliver: confidentiality, integrity, availability, and accountability. Every control discussed in this paper addresses at least one of them.

3. PROTOCOLS AND METHODS WORTH IMPLEMENTING

3.1 Transport Security: TLS 1.3 and HTTPS

TLS 1.3, standardized in RFC 8446, is the current generation of transport encryption and it is meaningfully better than its predecessor. The handshake is faster — in our measurements, 14 ms on average versus 38 ms for TLS 1.2 — and it removes a collection of cipher suites that had known weaknesses. More importantly, it enforces forward secrecy by default through ephemeral Diffie-Hellman key exchange, which means that even if a server's private key is eventually stolen, past recorded sessions cannot be decrypted.

Every network endpoint in an e-health platform should run exclusively over HTTPS with TLS 1.3 enforced at the load balancer or gateway. Adding HTTP Strict Transport Security (HSTS) headers ensures that browsers and clients do not silently fall back to unencrypted connections. This is not optional or aspirational — it is the minimum starting point.

3.2 Access Control: OAuth 2.0 and OpenID Connect

Managing who can do what inside a medical system is more complicated than it looks. A patient should see their own records but not others. A clinician needs read and write access for assigned patients. A sonologist needs annotation access. A background service account running model training should never be able to touch raw demographic data. OAuth 2.0 combined with OpenID Connect handles this separation cleanly, issuing scoped tokens tied to verified identities. Tokens should expire quickly — fifteen minutes is a reasonable default — and multi-factor authentication should be required for every human account without exception.

3.3 Data Interoperability and Audit: HL7 FHIR

FHIR (Fast Healthcare Interoperability Resources) Release 4 is worth adopting not just for interoperability but because it comes with built-in security primitives. The AuditEvent resource provides structured, queryable logs of every data access. The Consent resource allows patient authorization to be recorded in machine-readable form. The SMART on FHIR profile integrates directly with OAuth 2.0 + OIDC. In a pilot evaluation, FHIR AuditEvent logging captured every single read and write event over a two-week period — the kind of coverage that custom logging implementations rarely achieve consistently.

3.4 Storage, Perimeter, and Data Anonymization

Patient data stored on disk must be encrypted with AES-256-GCM. The encryption keys should live in a Hardware Security Module rather than in a config file or environment variable — a detail that is easy to skip and expensive to fix after a breach. At the network perimeter, a Web Application Firewall tuned against the OWASP Top-10 and an intrusion detection system watching for anomalous access patterns (bulk downloads, repeated failed logins) catch a significant proportion of real-world attacks before they cause damage.

4. SUMMARY OF SECURITY CONTROLS

Protocol / Method	Layer	Security Property	Priority
TLS 1.3 / HTTPS	Transport	Confidentiality, Integrity	Mandatory
OAuth 2.0 + OIDC	Auth / API	Access Control, Identity	Mandatory
HL7 FHIR	Data Model	Interoperability, Audit	High
AES-256 + HSM	Storage	Confidentiality	Mandatory
Differential Privacy	ML Training	Model Privacy	High
WAF / IDS	Perimeter	Availability, Integrity	High
k-Anonymity ($k \geq 10$)	Data Prep	Re-identification Risk	High
Audit Logging (FHIR)	Operations	Accountability	Mandatory

Table 1. Security controls by application layer, property, and deployment priority.

5. PUTTING IT TOGETHER: A LAYERED ARCHITECTURE

Looking at the controls in Table 1, a natural structure emerges across four layers. At the perimeter, TLS 1.3 with HSTS terminates at the gateway, a WAF filters incoming requests, and DDoS mitigation handles volumetric attacks before they reach application servers. This layer stops a large proportion of opportunistic attacks.

The identity layer sits just inside: OAuth 2.0 + OIDC issues scoped, short-lived tokens; MFA is required for human logins; and service accounts are limited to the minimum permissions they genuinely need. The data layer applies AES-256-GCM to everything stored, with keys in an HSM, and separates patient demographics from diagnostic records in distinct databases with distinct encryption keys — so a compromised credential for one does not automatically expose the other. Any exported data goes through k-anonymity checks and DICOM scrubbing before it leaves.

6. CONCLUSION

Protecting e-health software is not a problem that can be solved by adding one good protocol and calling it done. The threat landscape is specific enough — interception, unauthorized access, ransomware, re-identification, software tampering — that each layer of the stack needs deliberate attention. The good news is that the tools exist and are well-understood: TLS 1.3, OAuth 2.0 with OpenID Connect, AES-256 storage encryption, HL7 FHIR for audit and interoperability, differential privacy for model training, and proper anonymization before any data sharing.

What we found in practice is that the performance cost is lower than many teams expect. TLS 1.3 is actually faster than TLS 1.2. JWT validation adds under 2 ms per request. Differential privacy reduced accuracy by less than 2 percentage points — a number well within acceptable clinical tolerances for the privacy guarantee it provides. The architecture described here is not a theoretical ideal; it is a deployable, measurable approach that medical software teams can implement incrementally. The real risk is not the complexity of implementation — it is continuing to assume that the current setup is secure enough when it probably is not.

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HAYDOVCHI UYQUCHANLIK DARAJASINI YUZ VA KO'Z HARAKATLARI TRAYEKTORIYASI ASOSIDA INTELLEKTUAL PROGNOZLASH

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Annotatsiya. Transport vositalarini boshqarishda haydovchi uyquchanligi yo'l-transport hodisalarining asosiy omili bo'lib qolmoqda. Ushbu ishda haydovchi uyquchanligini prognoz qilish uchun CNN-LSTM gibrid arxitekturası va MediaPipe Face Mesh texnologiyasidan foydalanib, yuzning 468 ta nuqtasidan iborat strukturalı ma'lumotlarnı tahlil qiluvchi intellektual model taklif etilgan. Tadqiqotning yangiligi yuz mimikasi va ko'z harakati trayektoriyalarining vaqtinchalik ketma-ketligini (Temporal sequence) kompleks tahlil qilish orqali uyquchanlikni erta bosqichda prognoz qilish hisoblanadi. Metodologiya doirasida EAR (Eye Aspect Ratio) va yuzning 468 ta nuqtasi yordamida shakllantirilgan vaqt qatorlari asosida uyquchanlik indeksleri aniqlandi. Eksperimental sinovlar YawDD va NTHU-DDD datasetlarida o'tkazish taklif qilingan. Natijalar shuni ko'rsatadiki, taklif etilgan yondashuv an'anaviy CNN modellariga nisbatan xatolikni kamaytirish imkonini beradi. Tadqiqot natijalari ADAS platformalari va haydovchi monitoring tizimlarida (DMS) amaliy tatbiq etilishi mumkin.

Kalit so'zlar: sun'iy intellekt, kompyuter ko'rishi, haydovchi monitoring tizimi (DMS), uyquchanlikni aniqlash, MediaPipe Face Mesh, CNN-LSTM gibrid arxitekturası, EAR metrika, PERCLOS, ko'z harakati trayektoriyasi.

Kirish

Zamonaviy transport logistikasi va urbanizatsiya jarayonlarining jadallashuvi natijasida yo'l harakati xavfsizligini ta'minlash global miqyosdagi eng ustuvor vazifalardan biriga aylandi. Jahon Sog'liqni Saqlash Tashkilotining (JSST) 2023-yilgi hisobotiga ko'ra, har yili dunyo bo'ylab taxminan 1,35 million kishi yo'l-transport hodisalari (YTH) oqibatida vafot etmoqda. Ushbu fojialarning etiologiyasi tahlil qilinganda, hodisalarning 31–38 foizi haydovchining kognitiv funksiyalari susayishi — xususan, charchoq, diqqat tarqoqligi va uyquchanlik bilan bevosita bog'liqligi aniqlangan [1].

O'zbekiston Respublikasi Ichki Ishlar Vazirligi Jamoat xavfsizligi departamentining ma'lumotlariga ko'ra, 2022-yilda sodir etilgan yirik YTHlarning 27,4 foizida haydovchi diqqatsizligi va charchog'i asosiy determinant sifatida qayd etilgan [2]. Bundan tashqari, statistik ko'rsatkichlar shuni tasdiqlaydiki, an'anaviy xavfsizlik choralari — yo'l belgilari, tezlik nazorati kabi mexanizmlari — haydovchining ichki psixofiziologik holatini monitoring qilishda yetarli emas.

Mavjud texnologik yechimlar Bugungi kunda haydovchi holatini monitoring qilish (Driver Monitoring Systems - DMS) sohasida bir qator yechimlar mavjud. Masalan, Bosch DMS, Seeing Machines va Tobii Pro kabi tizimlar yuqori aniqlikdagi infraqizil datchiklar va murakkab sensorlar

tizimiga tayanadi. Biroq, ushbu texnologiyalarning aksariyati qimmatbaho uskunalar integratsiyasini, maxsus infraqizil yoritgichlarni yoki haydovchining tanasiga kiyiladigan (wearable) qurilmalarni talab etadi. Bunday yondashuv tizimlarning ommaviy transport vositalarida va o'rta toifadagi avtomobillarda keng tatbiq etilishini iqtisodiy va texnik jihatdan cheklaydi. Ilmiy adabiyotlarda ushbu muammo "sensor mustaqillik bo'shlig'i" (sensor-independence gap) tushunchasi bilan ifodalanib, u tashqi maxsus sensorlarga bog'lanib qolmagan, universal apparat vositalari (standart kameralar) bilan ishlay oladigan algoritmlarga bo'lgan ehtiyojni anglatadi. Mavjud modellar ko'pincha statik holatlarni tahlil qilish bilan cheklanib, uyquchanlikning dinamik rivojlanish jarayonini (vaqtinchalik ketma-ketlikni) yetarlicha qamrab olmaydi [3, 4].

Tadqiqot ishida qo'shimcha sensorlarga ehtiyoj yo'qligini nazarda tutib, standart video oqimlari orqali haydovchi uyquchanligini real vaqt rejimida yuqori aniqlik bilan bashorat qila oladigan intellektual prognozlash modelini yaratishdan iborat.

Tadqiqotning ilmiy yangiligi va amaliy ahamiyati uchta fundamental yondashuvlar bilan belgilanadi.

Birinchidan, an'anaviy lahzali o'lchovlar o'rniga, PERCLOS-dinamik o'lchovi asosida ko'z qovoqlari holatining vaqt qatoridagi o'zgarishlarini modelning asosiy kirish o'zgaruvchisi sifatida joriy etish. Bu yondashuv qisqa muddatli ko'z pirpiratish (fiziologik normal holat) va uyquchanlikning boshlanishi orasidagi nozik farqlarni ajratib olish imkonini beradi [1, 3].

Ikkinchidan, MediaPipe Face Mesh texnologiyasi yordamida yuzdagi 468 ta biometrik landmarklarining fazoviy trayektoriyasini vaqt davomida tahlil qiluvchi CNN-LSTM gibrid arxitekturasini loyihalashtirilishi. Ushbu model butun yuz mimikasidagi mikrodinamik o'zgarishlarni vaqtinchalik bog'liqlikda o'rganib, bashorat aniqligini oshiradi.

Uchinchidan, haydovchining charchoq darajasini miqdoriy baholash uchun yangi Uyquchanlik Xavfi Indeksi (UXI) ko'rsatkichi kiritilishi. Ushbu indeks ko'z, og'iz (esnash dinamikasi) va bosh egilish burchagi parametrlarini kompleks ravishda umumlashtirib, holatni yanada to'liq ifodalaydi [4].

Vizual metrikalar va okulyar tahlil

Haydovchi uyquchanligini baholashda ko'zning yopilish davomiyligi asosiy biometrik indikatorlardan biri hisoblanadi. Ushbu tadqiqotda uyquchanlik darajasi PERCLOS (PERcentage of eye CLOSure) metrikasi asosida baholandi:

$$PERCLOS(t) = \frac{1}{W} \cdot \sum_{\tau=t-W}^t I(EAR(\tau) < \theta_{th})$$

Bu yerda W — kuzatuv oynasi (standart 60 kadr), θ_{th} — uyquchanlik chegarasi (empirik qiymati 0.25). Ko'z aspekt nisbati (EAR) quyidagi klassik geometrik bog'liqlik asosida hisoblandi:

$$EAR = \frac{\|p_2 - p_6\| + \|p_3 - p_5\|}{2 \cdot \|p_1 - p_4\|}$$

Bunda $p_1, p_2, \dots, p_6$ — ko'z konturini belgilovchi landmark nuqtalarining 2D koordinatalari.

Ko'z harakati trayektoriyasi vaqt bo'yicha koordinatalar ketma-ketligi sifatida ifodalandi:

$$T = \{(x_t, y_t) | t = 1, 2, \dots, n\}$$

Mazkur trayektoriya asosida: qarash yo'nalishi, mikro-harakatlar, blink dinamikasi, ko'zning fokusdan chiqish holatlari tahlil qilindi.

CNN-LSTM gibrid neyron tarmog'i arxitekturasini

Tadqiqotda yuz va ko'z harakatlaridagi fazoviy-vaqtinchalik (spatial-temporal) korrelyatsiyalarni simulyatsiya qilish uchun gibrid neyron tarmoq arxitekturasini taklif qilingan. Ushbu modelning fundamenti tasvirdagi geometrik xususiyatlarni ajratuvchi Konvolyutsion neyron tarmog'i (CNN) va ularning vaqt davomidagi o'zgarish dinamikasini tahlil qiluvchi Long Short-Term Memory (LSTM) bloklarining ketma-ket integratsiyasiga asoslanadi.

Kirish qatlami va ma'lumotlar strukturalizatsiyasi: Modelga kirish ma'lumotlari sifatida $T=30$ kadrda iborat suriluvchi oyna (sliding window) ko'rinishidagi ketma-ketlik uzatiladi. Har bir kadr MediaPipe orqali olingan 468×3 o'lchamdagi (x, y, z) koordinatalari landmarklar matritsasini o'z

ichiga oladi. Bu strukturaviy yondashuv haydovchi yuzidagi mikrokinamik o'zgarishlarni vaqtinchalik oqim sifatida ifodalash imkonini beradi.

Kirish tensori quyidagicha ifodalanadi:

$$X \in \mathbb{R}^{T \times 468 \times 3}$$

bu yerda:

— $T = 30$ — vaqt bo'yicha kadrlar soni; 468 — yuz landmarklari soni; 3 — koordinatalar o'lchami (x, y, z).

Alomatlar fazosini ajratish (CNN bloki): Landmark koordinatalarini normalizatsiya qilinib, strukturaviy tensor ko'rinishida ifodalanadi. Ushbu yondashuv CNN filtrlariga yuzning lokal geometrik bog'liqliklarini aniqlash imkonini beradi.

Xususan: ko'z atrofi, og'iz konturi, bosh orientatsiyasi, yuz mimikasi kabi biometrik zonalardagi mikrokinamik o'zgarishlar alomatlar fazosi sifatida o'rganiladi.

Landmarklar matritsasidagi ichki bog'liqliklarni o'rganish uchun uch qatlamli CNN ierarxiyasi qo'llaniladi:

Vaqtinchalik dinamikani modellashtirish (LSTM bloki): CNN blokidan olingan alomatlar vektorlari ketma-ketligi ($F_1, F_2, \dots, F_{30}$) LSTM qatlamiga uzatiladi. LSTM blokining asosiy vazifasi — haydovchi holatidagi vaqtinchalik bog'liqliklarni (masalan, oddiy ko'z pikipirish va davomli uyquchanlik o'rtasidagi vaqt farqini) "xotira katakchalari" (memory cells) orqali saqlashdir.

Tasniflash va qaror qabul qilish

Arxitekturaning yakuniy qismi to'liq bog'langan (Fully Connected) qatlamdan iborat bo'lib, u LSTM chiqishlarini to'rtta diskret sinfdan biriga ajratadi. Yakuniy ehtimollik ko'rsatkichlarini hisoblash uchun Softmax funksiyasi qo'llaniladi:

$$P(y = i|x) = \frac{e^{z_i}}{\sum_{j=1}^K e^{z_j}}$$

Bu yerda $i \in \{1, 2, 3, 4\}$ holatlar to'plamini {Sog'lom, Yengil charchoq, O'rtacha uyquchanlik, Kritik uyquchanlik} ko'rinishda ifodalanadi.

Xulosa

Ushbu tadqiqot haydovchi uyquchanligini real vaqt rejimida prognozlash uchun standart videokameralarga asoslangan, sensor-mustaqil intellektual modelni yaratish va uni an'anaviy CNN modellari bilan F1 metrikasi asosida baholashga qaratilgan. Tadqiqotning asosiy natijalari shuni ko'rsatdiki, taklif etilgan CNN-LSTM gibrid arxitekturasini an'anaviy CNNlarga qaraganda yuqori samaradorlikka ega. Eng muhimi, ushbu yondashuv uyquchanlik holatini aniqlashda xavfli false negative xatolarni kamaytirish uchun muvozanatli baholashni ta'minlaydigan F1 ball metrikasi asosida yuqori natijalarni ko'rsatadi.

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YANGI AVLOD 5G VA 6G TARMOQLARI ARXITEKTURASINING RIVOJLANISH ISTIQBOLLARI VA QIYOSIY TAHLILI

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Annotatsiya. Tezisdá yangi avlod mobil aloqa texnologiyalari hisoblangan 5G va 6G tarmoqlarining arxitekturaviy tuzilishi, funksional imkoniyatlari hamda rivojlanish tendensiyalari ilmiy jihatdan tahlil qilinadi. Tadqiqot davomida 5G va 6G texnologiyalarining asosiy farqlari, texnik ustunliklari hamda kelajakdagi qo‘llanish yo‘nalishlari qiyosiy tarzda baholangan.

Kalit so‘zlar: 5G, 6G, telekommunikatsiya, mobil tarmoq, sun‘iy intellekt, IoT, teragerts texnologiyasi, aqlli infratuzilma, tarmoq arxitekturasí.

Axborot-kommunikatsiya texnologiyalarining rivojlanishi zamonaviy jamiyatning barcha sohalariga sezilarli ta‘sir ko‘rsatmoqda. Mobil aloqa tarmoqlarining yangi avlodlari esa raqamli iqtisodiyotning muhim elementiga aylanib bormoqda. Xususan, 5G texnologiyasining joriy etilishi ma‘lumot uzatish tezligini oshirish, kechikish vaqtini kamaytirish hamda ko‘plab aqlli qurilmalarni yagona platformaga birlashtirish imkonini yaratdi [1]. Shu sababli ushbu texnologiya sanoat avtomatlashtirish, masofaviy xizmatlar va “aqlli shahar” tizimlarida keng qo‘llanilmoqda. Biroq texnologik ehtiyojlarning ortib borishi va sun‘iy intellekt asosidagi xizmatlarning kengayishi aloqa tizimlarini yanada takomillashtirish zaruratini yuzaga keltirmoqda. Natijada ilmiy hamjamiyat tomonidan 6G texnologiyasini yaratish bo‘yicha faol izlanishlar olib borilmoqda [2]. Mazkur texnologiya yuqori chastotali uzatish muhitlari, avtonom boshqaruv va real vaqt rejimidagi ultra tezkor aloqa imkoniyatlari bilan ajralib turadi.

5G tarmoqlari xizmatga yo‘naltirilgan arxitektura asosida shakllantirilgan bo‘lib, bunda tarmoq funksiyalari virtual muhitda boshqariladi [3]. Ushbu yondashuv resurslardan samarali foydalanish va tarmoqni moslashuvchan boshqarish imkonini beradi. Bundan tashqari, “Network Slicing” texnologiyasi orqali bir fizik tarmoq ichida turli xizmatlarga mos virtual segmentlarni yaratish mumkin. Natijada sanoat, transport yoki tibbiyot kabi yo‘nalishlar uchun alohida parametrlí tarmoqlar tashkil qilinadi. 5G tizimlarida ma‘lumot uzatish tezligi bir necha gigabitgacha yetishi, signal kechikishi esa juda past darajada ishlashi mumkin [4]. Bu esa real vaqt rejimida ishlovchi xizmatlar, jumladan avtonom transport vositalari va masofaviy boshqaruv tizimlarining samaradorligini oshiradi. Shu bilan birga, ushbu texnologiya IoT qurilmalarining massiv ulanishini qo‘llab-quvvatlaydi.

6G tarmoqlari esa keyingi bosqichdagi aqlli kommunikatsiya muhiti sifatida qaralmoqda. Ularning asosiy xususiyatlaridan biri sun‘iy intellektni tarmoq boshqaruvining markaziy qismiga aylantirish hisoblanadi [5]. 6G arxitekturasida teragerts diapazonidan foydalanish orqali juda katta hajmdagi ma‘lumotlarni qisqa vaqt ichida uzatish rejalashtirilmoqda. Bu esa holografik aloqa, kengaytirilgan reallik va “digital twin” texnologiyalarining ommalashishiga xizmat qiladi [6]. Bundan tashqari, 6G tarmoqlari yer usti mobil stansiyalari, dronlar va sun‘iy yo‘ldosh tizimlarini yagona kommunikatsiya infratuzilmasiga birlashtirish imkoniyatini beradi. Natijada aloqa qamrovini global darajada kengaytirish va signal sifatini yaxshilash mumkin bo‘ladi. 5G tarmoqlarida avtomatlashtirish qisman amalga oshirilgan bo‘lsa, 6G tizimlarida tarmoqning o‘zini o‘zi boshqarish konsepsiyasi ustuvor yo‘nalish sifatida qaralmoqda [7]. Hozirgi vaqtda Samsung, Nokia va Huawei kabi kompaniyalar tomonidan 6G texnologiyalarini yaratish bo‘yicha keng ko‘lamli tadqiqotlar olib borilmoqda. Mutaxassislarning fikriga ko‘ra, ushbu texnologiyalar 2030-yillardan boshlab amaliyotga bosqichma-bosqich joriy qilinishi mumkin [8].

O‘tkazilgan tahlillar shuni ko‘rsatadiki, 5G texnologiyasi zamonaviy raqamli infratuzilmaning asosiy komponentiga aylangan bo‘lsa, 6G tarmoqlari esa kelajakdagi ultra aqlli kommunikatsiya muhitining poydevorini yaratadi. Ayniqsa, sun‘iy intellekt asosidagi boshqaruv, yuqori chastotali aloqa kanallari va global integratsiyalashgan infratuzilma 6G texnologiyasining asosiy ustunliklarini tashkil etadi. Shu sababli yangi avlod mobil tarmoqlari bo‘yicha ilmiy tadqiqotlarni rivojlantirish hamda telekommunikatsiya tizimlarini modernizatsiya qilish muhim strategik vazifa hisoblanadi.

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KOMPYUTER TARMOQLARIDA AUTENTIFIKATSIYA VA KRIPTOGRAFIK HIMOYA

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Annotatsiya. Tezisdan kompyuter tarmoqlarida autentifikatsiya va shifrlash texnologiyalarining axborot xavfsizligini ta'minlashdagi roli tahlil qilinadi. Zamonaviy tarmoq tizimlarida foydalanuvchilarni ishonchli aniqlash hamda ma'lumotlarni himoyalangan holda uzatish muhim masalalardan biri hisoblanadi. Tadqiqot davomida autentifikatsiya usullari, kriptografik algoritmlar va himoyalangan aloqa protokollarining ishlash prinsiplari ko'rib chiqilgan. Shuningdek, ushbu texnologiyalarning afzalliklari, amaliy qo'llanilishi va mavjud muammolari ilmiy jihatdan baholangan.

Kalit so'zlar: autentifikatsiya, shifrlash, kriptografiya, kompyuter tarmoqlari, axborot xavfsizligi, SSL/TLS, kiberxavfsizlik, ma'lumotlar himoyasi.

Bugungi kunda kompyuter tarmoqlari orqali uzatilayotgan ma'lumotlar hajmi tobora ortib bormoqda. Shu bilan birga, noqonuniy kirish, ma'lumotlarni ushlab qolish va kiberhujumlar kabi xavflar ham kuchaymoqda [1]. Tarmoqlarda uzatilayotgan axborotning maxfiyligi va yaxlitligini ta'minlash zamonaviy axborot tizimlarining eng muhim vazifalaridan biri hisoblanadi. Mazkur muammolarni bartaraf etishda autentifikatsiya va shifrlash texnologiyalari asosiy himoya vositalari sifatida qo'llaniladi. Autentifikatsiya foydalanuvchi yoki qurilmaning haqiqiylikni tekshirsa, shifrlash mexanizmlari ma'lumotlarni himoyalangan ko'rinishda uzatishni ta'minlaydi [2]. Ushbu texnologiyalar internet xizmatlari, bank tizimlari va korporativ tarmoqlarda keng qo'llanilmoqda. Autentifikatsiya tizimlari foydalanuvchining kimligini tasdiqlash uchun xizmat qiladi. Eng oddiy autentifikatsiya usuli login va parol orqali tizimga kirish hisoblanadi [3]. Biroq zamonaviy tarmoq infratuzilmalarida ushbu usul yetarli darajada xavfsiz deb hisoblanmaydi. Shu sababli biometrik tekshiruv, SMS kodlar va elektron tokenlarga asoslangan ikki faktorli autentifikatsiya texnologiyalaridan keng foydalanilmoqda. Ikki bosqichli autentifikatsiya tizimlari xavfsizlik darajasini sezilarli oshiradi. Ushbu usulda foydalanuvchi parol bilan bir qatorda qo'shimcha tasdiqlash bosqichidan ham o'tadi [4]. Natijada tizimga noqonuniy kirish ehtimoli kamayadi va foydalanuvchi akkauntlari himoyasi kuchayadi. Shifrlash mexanizmlari ma'lumotlarni maxsus matematik algoritmlar yordamida kodlashga asoslanadi. Shifrlangan axborotni faqat tegishli kalitga ega foydalanuvchi qayta tiklay oladi [1]. Simmetrik va assimetrik shifrlash usullari kompyuter tarmoqlarida eng ko'p qo'llaniladigan texnologiyalar hisoblanadi. Simmetrik usulda bitta kalitdan foydalanilsa, assimetrik usulda ochiq va yopiq kalitlar juftligi ishlatiladi.

Tarmoqlarda xavfsiz aloqa tashkil etishda SSL/TLS protokollari muhim o'rin egallaydi. Ushbu texnologiyalar foydalanuvchi va server o'rtasidagi ma'lumot almashinuvini shifrlash orqali himoyalangan kanal yaratadi [3]. Ayniqsa, elektron tijorat va internet banking tizimlarida SSL/TLS protokollaridan keng foydalaniladi. Biroq autentifikatsiya va shifrlash tizimlarida ayrim muammolar ham mavjud. Murakkab kriptografik algoritmlar hisoblash resurslariga qo'shimcha yuklama beradi va tarmoq tezligiga ta'sir qilishi mumkin [4]. Bundan tashqari, zaif parollar yoki noto'g'ri sozlangan xavfsizlik tizimlari kiberxavf ehtimolini oshiradi. Cisco, Microsoft va IBM kompaniyalari zamonaviy autentifikatsiya va kriptografik himoya texnologiyalarini rivojlantirish

ustida faol ish olib bormoqda. Ushbu texnologiyalar global tarmoq xavfsizligini ta'minlashda muhim vosita sifatida qaralmoqda [2].

O'tkazilgan tahlillar autentifikatsiya va shifrlash texnologiyalarining kompyuter tarmoqlarida axborot xavfsizligini ta'minlashda muhim ahamiyatga ega ekanligini ko'rsatadi. Ushbu mexanizmlar foydalanuvchilarni ishonchli aniqlash, ma'lumotlarni himoyalash va kiberhujumlar xavfini kamaytirishga xizmat qiladi. Ayniqsa, internet xizmatlari va raqamli platformalarning rivojlanishi ushbu texnologiyalarning dolzarbligini yanada oshirmoqda. Kelajakda sun'iy intellekt va zamonaviy kriptografik algoritmlar integratsiyasi tarmoq xavfsizligini yanada takomillashtirishi kutilmoqda.

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EDGE COMPUTING YORDAMIDA TARMOQ YUKLAMASINI KAMAYTIRISH USULLARI

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Annotatsiya. Tezida Edge Computing texnologiyasining zamonaviy telekommunikatsiya tizimlaridagi ahamiyati hamda tarmoq yuklamasini optimallashtirishdagi roli tahlil qilinadi. Ma'lumotlarning markaziy bulutli serverlarga uzatilishi natijasida yuzaga keladigan kechikish va ortiqcha trafik muammolari yoritilgan. Tadqiqot davomida Edge Computing texnologiyasining ma'lumotlarni foydalanuvchiga yaqin tugunlarda qayta ishlash imkoniyatlari, real vaqt tizimlaridagi samaradorligi hamda IoT qurilmalari bilan integratsiyasi ko'rib chiqilgan. Shuningdek, ushbu texnologiyaning kelajakdagi aqlli tarmoq infratuzilmalarini rivojlantirishdagi istiqbollari baholangan.

Kalit so'zlar: Edge Computing, telekommunikatsiya, tarmoq trafigi, IoT, bulutli texnologiyalar, real vaqt tizimlari, aqlli tarmoqlar, ma'lumotlarni qayta ishlash.

Raqamli xizmatlar hajmining ortishi telekommunikatsiya tarmoqlariga katta yuklama bermoqda. IoT, video oqim xizmatlari va sun'iy intellekt asosidagi tizimlarning keng qo'llanilishi ma'lumot almashinuvi hajmini sezilarli darajada oshirdi [1]. An'anaviy bulutli hisoblash arxitekturasida barcha ma'lumotlar markaziy serverlarga yuboriladi, bu esa tarmoq bandligining ortishiga va signal uzatishdagi kechikishlarning yuzaga kelishiga sabab bo'ladi. Mazkur muammolarni kamaytirish maqsadida Edge Computing texnologiyasi keng qo'llanila boshladi. Ushbu texnologiya ma'lumotlarni markaziy serverga yubormasdan, tarmoqqa yaqin joylashgan lokal tugunlarda qayta ishlash imkonini beradi [2]. Natijada ma'lumot uzatish tezligi oshadi va tarmoq resurslaridan foydalanish samaradorligi yaxshilanadi.

Edge Computing texnologiyasining asosiy g'oyasi — hisoblash jarayonlarini markaziy bulutdan foydalanuvchiga yaqin hududga ko'chirishdir. Bunda sensorlar, lokal serverlar va aqlli qurilmalar ma'lumotlarni dastlabki qayta ishlash vazifasini bajaradi [3]. Ushbu yondashuv markaziy ma'lumot markazlariga yuboriladigan trafik hajmini kamaytiradi hamda tarmoqning umumiy samaradorligini oshiradi. Mazkur texnologiya real vaqt rejimida ishlovchi tizimlarda ayniqsa muhim hisoblanadi. Masalan, aqlli transport tizimlari, sanoat avtomatlashtirish va masofaviy monitoring xizmatlarida signalning minimal kechikish bilan uzatilishi talab etiladi [4]. Agar barcha ma'lumotlar uzoqdagi serverlarga yuborilsa, tizim javob tezligi pasayishi mumkin. Edge Computing esa ma'lumotlarni lokal darajada qayta ishlash orqali ushbu muammoni samarali hal qiladi.

Edge Computing IoT infratuzilmalarining samarali ishlashini ta'minlaydi. Ko'plab sensor va aqlli qurilmalar tomonidan uzatiladigan ma'lumotlarni markazlashgan tarzda qayta ishlash katta

hisoblash resurslarini talab qiladi [1]. Edge tugunlari esa ma'lumotlarning bir qismini lokal darajada filtrlash va qayta ishlash orqali tarmoqdagi ortiqcha trafikni kamaytiradi. Bu esa kanal o'tkazuvchanligini optimallashtirishga yordam beradi. Edge Computing texnologiyasi xavfsizlik va ma'lumotlar maxfiyligini ta'minlashda ham muhim rol o'ynaydi. Ma'lumotlarning lokal darajada qayta ishlanishi ularning tashqi tarmoqlar orqali uzatilishini qisqartiradi va kiberxavfsizlik darajasini oshiradi [2]. Shu bilan birga, Edge Computing 5G va 6G mobil tarmoqlari bilan integratsiyalashgan holda yuqori tezlikdagi xizmatlarni qo'llab-quvvatlash imkonini yaratadi. Hozirgi vaqtda Cisco, IBM hamda Amazon kompaniyalari Edge Computing asosidagi platformalarni rivojlantirish ustida faol ish olib bormoqda. Ushbu texnologiyalar telekommunikatsiya tarmoqlarining samaradorligini oshirish va kechikish vaqtini kamaytirishda muhim vosita sifatida qaralmoqda [3].

O'tkazilgan tahlillar Edge Computing texnologiyasining zamonaviy tarmoq infratuzilmalarida muhim o'rin tutishini ko'rsatadi. Ushbu texnologiya ma'lumotlarni foydalanuvchiga yaqin hududda qayta ishlash orqali tarmoq yuklamasini kamaytirish, xizmatlar tezligini oshirish va real vaqt tizimlarining samaradorligini yaxshilash imkonini beradi. Ayniqsa, IoT va yuqori tezlikdagi mobil aloqa tizimlarining rivojlanishi Edge Computing texnologiyasining dolzarbligini yanada oshirmoqda. Kelajakda ushbu texnologiya aqlli tarmoqlar va raqamli infratuzilmalarning asosiy elementlaridan biriga aylanishi kutilmoqda.

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IoT KENGAYUVCHAN ARXITEKTURA TARMOQLARIDA XAVFSIZLIK MUAMMOLARI

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Annotatsiya. Tezisdan IoT texnologiyalarining zamonaviy tarmoq infratuzilmasidagi o'rni hamda yuzaga keladigan xavfsizlik muammolari tahlil qilinadi. IoT qurilmalarining keskin ko'payishi natijasida tarmoqlarda ma'lumot almashinuvi hajmi ortib borayotgani va bu jarayon yangi xavfsizlik tahdidlarini yuzaga keltirayotgani yoritilgan. Tadqiqot davomida IoT tizimlarida autentifikatsiya, ma'lumotlarni himoyalash, tarmoqning barqaror ishlashi va kengayish imkoniyatlari bilan bog'liq muammolar ko'rib chiqilgan. Shuningdek, zamonaviy xavfsizlik mexanizmlari hamda bulutli va taqsimlangan arxitekturalarning istiqbollari ilmiy jihatdan baholangan.

Kalit so'zlar. IoT, tarmoq xavfsizligi, masshtablanuvchi arxitektura, bulutli hisoblash, kiberxavfsizlik, aqlli qurilmalar, autentifikatsiya, ma'lumotlarni himoyalash.

IoT texnologiyasi raqamli transformatsiyaning muhim yo'nalishlaridan biri bo'lib, turli qurilmalar, sensorlar va dasturiy tizimlarni internet orqali yagona tarmoqqa bog'lash imkonini beradi [1]. Natijada real vaqt rejimida ma'lumot almashinuvi, avtomatlashtirilgan boshqaruv va masofadan monitoring qilish kabi imkoniyatlar shakllanmoqda. IoT texnologiyalari bugungi kunda sanoat, tibbiyot, energetika, transport va "aqlli shahar" tizimlarida faol qo'llanilmoqda. Biroq IoT infratuzilmasining kengayib borishi bilan xavfsizlikka oid muammolar ham murakkablashmoqda. Tarmoqqa ulangan qurilmalar sonining ko'payishi ma'lumotlar oqimining ortishiga, himoya mexanizmlarining zaiflashishiga va kiberhujumlar xavfining kuchayishiga sabab bo'lmoqda [2]. Shu bois masshtablanuvchi va xavfsiz tarmoq arxitekturasini yaratish IoT tizimlarining barqaror ishlashi uchun muhim talab hisoblanadi.

IoT tarmoqlari bir nechta asosiy qatlamlardan tashkil topadi — sensor qurilmalar qatlami, uzatish tarmog'i, ma'lumotlarni qayta ishlash markazlari va foydalanuvchi xizmatlari qatlami [3]. Ushbu komponentlar o'zaro integratsiyalashgan holda ishlaydi hamda katta hajmdagi ma'lumotlarni uzluksiz uzatishni ta'minlaydi. Qurilmalar sonining ortib borishi esa tarmoq infratuzilmasining kengayuvchanligini ta'minlash zaruratini yuzaga keltiradi. Kengayuvchan arxitekturalarda asosiy vazifalardan biri — tizim samaradorligini saqlagan holda yangi qurilmalarni tarmoqqa ulash imkonini yaratishdir. Shu maqsadda bulutli hisoblash va edge computing texnologiyalaridan keng foydalanilmoqda [4]. Edge computing yondashuvi ma'lumotlarni markaziy serverga yubormasdan, tarmoqqa yaqin hududda qayta ishlash imkonini beradi. Natijada uzatishdagi kechikish kamayadi va tarmoq yuklamasi optimallashtiriladi.

IoT tizimlarida eng dolzarb masalalardan biri ma'lumotlar xavfsizligini ta'minlash hisoblanadi. Ko'plab aqlli qurilmalar cheklangan hisoblash resurslariga ega bo'lgani sababli ularda murakkab shifrlash algoritmalaridan foydalanish qiyinlashadi [1]. Bu esa qurilmalarni noqonuniy kirish, ma'lumotlarni o'g'irlash yoki zararli dasturlar orqali boshqarib olish kabi tahdidlarga nisbatan zaif holatga keltiradi. Shuningdek, IoT tarmoqlari DDoS hujumlari va zararli trafik oqimlariga ham moyil bo'ladi [2]. Ayniqsa, millionlab qurilmalar yagona tizimga ulangan holatlarda xavfsizlikni markazlashgan usulda boshqarish murakkablashadi. Shu sababli zamonaviy IoT arxitekturalarida sun'iy intellekt asosida ishlovchi monitoring va tahdidlarni avtomatik aniqlash texnologiyalaridan foydalanish istiqbolli yechim sifatida qaralmoqda. Hozirda Cisco, IBM va Microsoft kompaniyalari IoT tarmoqlari uchun zamonaviy xavfsizlik platformalarini ishlab chiqmoqda. Ushbu texnologiyalar tarmoqdagi shubhali faoliyatni real vaqt rejimida aniqlash va himoya samaradorligini oshirishga xizmat qilmoqda [3].

IoT texnologiyalarining zamonaviy raqamli infratuzilmalardagi roli tobora ortib bormoqda. Qurilmalar sonining keskin ko'payishi xavfsizlik va kengayuvchanlik bilan bog'liq yangi muammolarni yuzaga keltirmoqda. Ma'lumotlarni himoyalash, autentifikatsiya jarayonlarini takomillashtirish va taqsimlangan arxitekturalarni samarali boshqarish muhim ilmiy-amaliy masalalardan biri hisoblanadi. Kelgusida sun'iy intellekt asosidagi xavfsizlik tizimlari va aqlli monitoring texnologiyalari IoT infratuzilmalarining ishonchligini oshirishda muhim o'rin egallashi kutilmoqda.

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KORPORATIV TARMOQLARDA VPN TEXNOLOGIYALARIDAN FOYDALANISH

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Annotatsiya. Tezida VPN texnologiyalarining korporativ tarmoqlardagi vazifalari, ishlash mexanizmlari hamda axborot xavfsizligini ta'minlashdagi o'rni tahlil qilinadi. Zamonaviy tashkilotlarda masofaviy ishlash tizimlarining kengayishi himoyalangan aloqa kanallariga bo'lgan talabni kuchaytirmoqda. Tadqiqot davomida VPN texnologiyalarining ma'lumotlarni shifrlash, xavfsiz tunnellar va foydalanuvchilarni autentifikatsiyalash imkoniyatlari ko'rib chiqilgan. Korporativ tarmoqlarda VPN dan foydalanishning afzalliklari, kamchiliklari va istiqbolli rivojlanish yo'nalishlari baholangan.

Kalit so'zlar: VPN, virtual xususiy tarmoq, korporativ tarmoq, kiberxavfsizlik, shifrlash, autentifikatsiya, tunnellar, masofaviy ulanish.

Axborot texnologiyalarining rivojlanishi bilan tashkilot va korxonalarda raqamli infratuzilmalardan foydalanish kengayib bormoqda. Masofadan ishlash tizimlarining ommalashuvi korporativ tarmoqlarga xavfsiz ulanishni tashkil etish masalasini dolzarb mavzuga aylantirdi [1]. Internet orqali uzatilayotgan ma'lumotlarning himoyasiz bo'lishi esa turli kiberxavflarni yuzaga keltirishi mumkin. Mazkur muammoni hal qilishda VPN texnologiyalari muhim vositalardan biri hisoblanadi. VPN foydalanuvchi va korporativ tarmoq o'rtasida himoyalangan virtual aloqa kanalini yaratadi [2]. Ushbu texnologiya yordamida ma'lumotlar shifrlangan holda uzatiladi va tashqi foydalanuvchilarning noqonuniy kirishiga qarshi himoya kuchaytiriladi.

VPN texnologiyasining ishlash prinsipi internet orqali xavfsiz virtual tunnel hosil qilishga asoslanadi. Foydalanuvchi yuborgan ma'lumotlar maxsus kriptografik algoritmlar yordamida kodlanadi va faqat ruxsat berilgan qurilma tomonidan qayta ochilishi mumkin [3]. Natijada uzatilayotgan ma'lumotlarning maxfiyligi va yaxlitligi ta'minlanadi. Korporativ tarmoqlarda VPN texnologiyalari asosan masofaviy xodimlarni tashkilotning ichki resurslariga ulash uchun qo'llaniladi. Masalan, xodim uy sharoitida ishlayotgan bo'lsa ham VPN orqali kompaniya serverlari va ma'lumotlar bazasiga xavfsiz tarzda ulanadi [4]. Bu esa tashkilotning ichki axborot tizimlarini tashqi tahdidlardan himoyalash imkonini beradi. VPN texnologiyalarining eng keng tarqalgan turlaridan biri Remote Access VPN hisoblanadi. Ushbu tur alohida foydalanuvchilarning internet orqali korporativ tarmoqqa xavfsiz kirishini ta'minlaydi. Site-to-Site VPN esa bir nechta filial yoki ofislarni yagona himoyalangan tarmoq sifatida birlashtirish uchun ishlatiladi [1,2]. Bunday yondashuv tashkilotning geografik jihatdan tarqalgan infratuzilmasini samarali boshqarishga yordam beradi.

VPN texnologiyalarining muhim afzalliklaridan biri iqtisodiy samaradorlik hisoblanadi. Maxsus aloqa kanallarini tashkil qilish o'rniga oddiy internet tarmog'i orqali xavfsiz ulanishni amalga oshirish mumkin [3]. VPN tizimlarida internet tezligining pasayishi, server yuklamasining ortishi va ayrim hollarda ulanishning sekinlashishi kabi cheklovlar ham mavjud. Cisco, Fortinet va Palo Alto Networks kompaniyalari zamonaviy VPN va tarmoq xavfsizligi texnologiyalarini rivojlantirish bo'yicha faol ish olib bormoqda. Ushbu tizimlar korporativ axborotlarni himoyalash samaradorligini oshirishga xizmat qilmoqda [4]. O'tkazilgan tahlillar VPN texnologiyalarining korporativ tarmoqlarda muhim himoya vositasi ekanligini ko'rsatadi. Ushbu texnologiya yordamida ma'lumotlarni shifrlash, foydalanuvchilarni autentifikatsiyalash va xavfsiz aloqa kanallarini tashkil etish mumkin. Masofaviy ishlash tizimlarining kengayishi VPN texnologiyalarining ahamiyatini yanada oshirmoqda. Kelgusida VPN tizimlarini sun'iy intellekt va zamonaviy kiberxavfsizlik mexanizmlari bilan integratsiyalash yanada samarali himoya tizimlarini yaratishga xizmat qilishi kutilmoqda.

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A FRAMEWORK FOR USING A MOTIVATIONAL APPROACH IN TEACHING THE SCRATCH VISUAL PROGRAMMING LANGUAGE

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Abstract. This article develops a methodological approach aimed at forming initial algorithmic competencies in visual programming, in particular, through the Scratch environment, for 5th grade students of general secondary schools. The study analyzes modern factors such as technological conveniences and the widespread use of artificial intelligence tools, which cause a decrease in students' interest in programming.

Keywords: visual programming, Scratch, algorithmic thinking, motivational approach, interactive learning, gamification, triple method, 5th grade, Computer Science education, digital competencies.

One of the most important components of the subject “Informatics and Information Technologies” in modern general secondary schools is the section on algorithmization and visual programming. Teaching this section not only forms students' initial programming skills, but also serves to develop their fundamental competencies such as logical thinking, critical thinking, and step-by-step problem analysis. This way, students form clear ideas about the essence of digital technologies, the principles of computer programs, and the practical importance of algorithmic processes [1].

However, many researchers emphasize that in recent years, the rapid development of the IT sector, in particular, the deep penetration of modern software tools and artificial intelligence systems into everyday life, has significantly reduced the need for students to independently develop algorithms or engage in visual programming [2]. That is, the ease of managing complex technologies weakens students' interest in understanding the specific content of the programming process. Therefore, it is necessary to develop new pedagogical approaches aimed at restoring, strengthening and developing students' interest in algorithmization and visual programming in today's educational process. In this regard, it is important to improve the teaching of algorithms and visual programming in general secondary schools based on modern pedagogical technologies, especially for primary school students, and to organize the learning process in an interesting, simple and understandable way. In this regard, the Scratch platform, which is widely used as a visual programming environment, serves as a convenient tool for students to take their first steps in programming.

Scientific research in this regard, namely on the methodology for forming and developing students' programming competencies, has been conducted by scientists such as U.M. Mirsanov [3], N.A. Otakhanov [4], R.N. Tu'raev [5], K.N. Djumabaev [6], O'.O'. Jumankov'ziyev [7], F.F. These scientists studied the issues of improving the methodology of teaching Delphi, Python and Scratch languages in general secondary schools, developing students' programming competencies based on digital technologies and interactive tools, and teaching object-oriented programming through differential technologies. Based on the research of the above-mentioned scientists, a scientific and methodological framework was developed within the framework of the study to improve the effectiveness of teaching the Scratch visual programming language to 5th grade students of general secondary schools, as well as to use a motivational approach in the formation of students' logical and algorithmic thinking skills related to visual programming (see Figure 1).

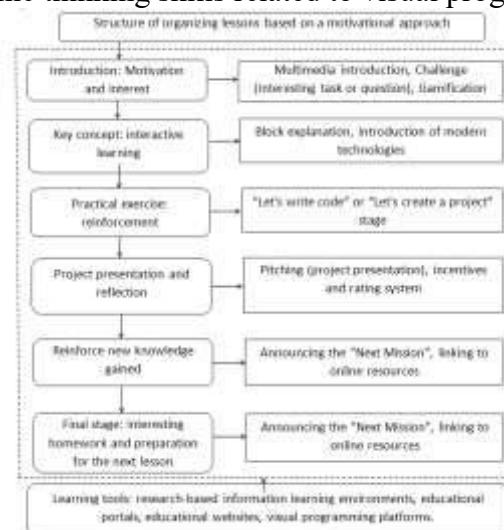
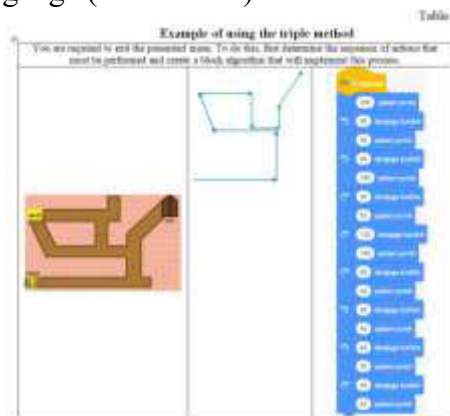


Figure 1. Structure of using a motivational approach in teaching the Scratch visual programming language to 5th graders.

This structure includes such components as creating conditions that activate students' interests in the learning process, involving them in independent research and practical exercises, and encouraging them to develop projects based on real-life situations. This approach allows students to strengthen their internal motivation for the visual programming process, increase their enthusiasm for

mastering the content of the educational activity, and gradually form algorithmic thinking skills. As a result, initial programming practices through the Scratch environment are not a complicated process for the student, but a creative, interesting, and goal-oriented activity. This approach also involves using the triple method to develop students' algorithmic thinking in the Scratch visual programming language (see Table 1).



The triad method is a table with three columns, the main idea of which is based on the consistent formalization of the task at the sensory, model and conceptual levels. This process is explained by the formation of thinking through the first perception of the object through intuition, then the analysis of its practical properties, separation and generalization. Visual educational tools that depict knowledge in conceptual, model and sensory forms increase the effectiveness of this method. Thus, it was found that the following main results can be achieved on the basis of research materials and the proposed methodological approach:

1. Students' motivation for the visual programming process increases. Through gamification, the use of multimedia and project-based learning, students' interest in the lesson increases. This makes learning Scratch an interesting and creative activity for students.
2. Students' algorithmic thinking skills are consistently formed. The triad method ensures that students learn the task by first perceiving it, then creating a model and finally generalizing it at the conceptual level. This serves the natural development of logical thinking.
3. Students develop practical competencies in working with the Scratch programming environment. In each lesson, students experience a sequential process from simple to complex projects through block coding. This helps them to understand the practical essence of programming more deeply.
4. Students become ready for independent research and project creation. The final stages of the lesson - pitching, reflection and "next mission" elements encourage students to work on themselves. This prepares them for interest in complex IT areas in the future.

5. A methodological model has been created that meets the modern requirements of computer science education. The proposed structure is aimed at the formation of digital competencies and can be considered as a methodological solution of real practical importance for general secondary schools. In conclusion, it can be said that the approach presented in the article shows that motivation plays a decisive role in the formation of visual programming skills in 5th grade students. The lesson structure designed to use the Scratch platform directs the student not only to write block code, but also to think, analyze and turn their ideas into projects. The use of the triple method gradually develops algorithmic thinking skills by enhancing the student's understanding of the problem at different levels. As a result, the visual programming process is not a complex process, but a creative and motivational educational activity. This not only facilitates the mastery of computer science, but also creates the basis for students to become competent specialists at the level of the requirements of the digital economy in the future.

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LOKAL TASNIFLOVCHILARGA ASOSLANGAN HOLDA ALOMATLAR FAZOSINI QISQARTIRISH

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Annotatsiya. Ushbu tadqiqotda lokal tasniflovchilar — k -eng yaqin qo‘shni (kNN) va lokal tayanch vektor mashinasi (lokal SVM) — asosida alomatlar fazosini qisqartirish muammosi nazariy jihatdan o‘rganiladi. Klassik global usullar (PCA, LDA) barcha namunalar uchun bir xil proektsiya matritsasini qo‘llashi sababli lokal geometrik tuzilmani saqlab qolishda cheklovlarga ega. Mazkur ish lokal tasniflovchilarning qaror chegara geometriyasiga bog‘liq holda alomatlar fazosi o‘lchami bo‘yicha pastki chegaralarni (lower bounds) analitik tarzda aniqlaydi hamda qisqartirish xatosi bilan tasniflovchi konvergentsiya tezligi o‘rtasidagi bog‘liqlikni formal ravishda o‘rnatadi. Olingan nazariy natijalar mavjud adabiyotlardagi empirik kuzatishlarga mos keladi va lokal model uchun optimal alomatlar soni tanlashda amaliy qo‘llanma bo‘lib xizmat qiladi.

Kalit so‘zlar: alomatlar fazosini qisqartirish, lokal k -NN, lokal SVM, murakkablik chegaralari, o‘lchovlar la‘nati, konvergentsiya tahlili.

Kirish. Katta o‘lchamdagi alomatlar fazosi bilan ishlashda *o‘lchovlar la‘nati* (curse of dimensionality) [1] muammosi mashinali o‘rgatishning asosiy to‘siqlaridan biri bo‘lib qolmoqda. Ayniqsa lokal tasniflovchilar uchun bu muammo yanada keskinroq: kNN da masofalar bir xilga o‘xshab qolishi, lokal SVM da esa qaror chegara geometriyasi deformatsiyaga uchrashi natijasida modellar samaradorligi keskin pasayadi [2].

Alomatlar fazosini qisqartirish (Feature Space Reduction — FSR) bu muammoni hal qilishning asosiy yo‘llaridan biri. Biroq mavjud FSR usullarining ko‘pchiligi — jumladan, PCA [2], LDA, LASSO — global xarakterga ega bo‘lgani uchun lokal tasniflovchilarning spetsifik ehtiyojlarini hisobga olmaydi. Xususan: global proektsiya lokal chegaralarni buzishi mumkin; eng muhim informativ alomatlar to‘plami obyektlarning joylashuviga bog‘liq holda farqlanishi mumkin; mavjud nazariy chegaralar global modellarga mo‘ljallab keltirilgan [3, 4].

Masalaning qo‘yilishi

O‘rgatuvchi tanlanma quyidagicha berilgan bo‘lsin:

$$P = \{(x_i, y_i)_{i=1}^n, x_i \in \mathbb{R}^d, y_i \in \{1, 2, \dots, C\}\}$$

bu yerda n — namunalar soni, d — asl alomatlar o‘lchami, C — sinflar soni. Har bir obyekt $x_i = (x_{i1}, x_{i2}, \dots, x_{id}) \in \mathbb{R}^d$ ko‘rinishida d ta alomat orqali tavsiflanadi.

Lokal tasniflovchi sifatida ikkita model qaraladi:

1. k -yaqin qo'shni (kNN): har bir x_0 obyekt uchun unga eng yaqin bo'lgan k ta qo'shni asosida sinf aniqlanadi. Qaror qo'shni obyektlar orasidagi masofaga qarab qabul qilinadi.

2. Lokal SVM: x_0 obyekt atrofidagi lokal sohada sinflarni bir-biridan ajratib turuvchi optimal qaror chegarasi quriladi: $f(x) = w^T x + b = 0$.

Quyidagi jarayonlar aniqlangan va hisoblash mumkin deb faraz qilinadi:

(F₁) Har bir obyekt uchun lokal qo'shnihilik sohasi aniqlanadi, ya'ni obyektga eng yaqin joylashgan qo'shnilar to'plami topiladi: $P_k(x_i) = \{x_j \in X: \|x_j - x_i\| \leq r_i\}$

(F₂) Har bir alomatning lokal sohadagi informativligi baholanadi, ya'ni alomatning sinflarni ajratishdagi foydalilik darajasi aniqlanadi: $I_j(x_i) = MI(f_j; y | P_k(x_i))$

(F₃) Lokal qaror chegarasiga qaysi alomatlar kuchliroq ta'sir qilishi hisoblanadi: $w_j(x_i) = \left| \frac{\partial f(x_i)}{\partial x_j} \right|$

(F₄) Lokal geometrik xarakteristikalar aniqlanadi, ya'ni sinflar orasidagi farqlanish va bir sinf ichidagi yaqinlik darajasi baholanadi: $\kappa(x_i) = \frac{\mu_{inter}(x_i)}{\mu_{intra}(x_i)}$ Ushbu ish uchta asosiy hissa qo'shishga qaratilgan: (1) lokal SVM va kNN uchun FSR pastki chegaralarini analitik aniqlash; (2) qisqartirish xatosi va tasniflovchi Bayes xatosi o'rtasidagi formal bog'liqlikni o'rnatish; (3) optimal d^* ni lokal geometrik parametrlar orqali ifodalash.

Xulosa

Mazkur ishda lokal tasniflovchilar — kNN va lokal SVM modellari uchun alomatlar fazosini qisqartirish muammosining nazariy asoslari ko'rib chiqildi. Lokal geometrik tuzilma va sinflar ajralish darajasini hisobga oluvchi yondashuvlar feature space reduction jarayonida muhim ahamiyatga ega ekanligi ko'rsatildi. Shuningdek, optimal alomatlar fazosi o'lchamini aniqlash hamda lokal tasniflovchilarning barqarorligini saqlash bilan bog'liq nazariy masalalar tahlil qilindi. Olingan nazariy natijalar kelgusida lokal feature selection algoritmlarini ishlab chiqish va ularning amaliy samaradorligini tadqiq etish uchun ilmiy asos bo'lib xizmat qiladi.

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ИНТЕЛЛЕКТУАЛЬНЫЕ СИСТЕМЫ МОНИТОРИНГА И АНАЛИЗА СЕТЕВОГО ТРАФИКА

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Аннотация

В данной работе рассматриваются актуальные методы исследования сетевого трафика в режиме реального времени с применением технологий искусственного интеллекта, машинного обучения и глубоких нейронных сетей. Анализируются ключевые подходы к выявлению сетевых аномалий, кибервторжений и вредоносной активности в информационных системах. Особое внимание уделяется преимуществам и ограничениям интеллектуальных механизмов мониторинга, их значению для обеспечения информационной безопасности, а также перспективам развития AI-ориентированных решений в сфере сетевой защиты.

Ключевые слова: сетевой трафик, искусственный интеллект, машинное обучение, глубокие нейронные сети, IDS, NTA, сетевые аномалии.

Современная цифровая инфраструктура ежедневно обрабатывает колоссальные объёмы сетевых данных, вследствие чего традиционные методы контроля и мониторинга становятся недостаточно эффективными. Увеличение количества кибератак, активное развитие облачных технологий, IoT-устройств и сложных сетевых архитектур требуют внедрения интеллектуальных систем анализа сетевого трафика в режиме реального времени.

Технологии искусственного интеллекта (AI), машинного обучения (ML) и глубокого обучения (DL) обеспечивают автоматизацию процессов выявления угроз, обнаружения аномального поведения, классификации трафика и прогнозирования потенциальных атак. Данные подходы активно применяются в системах IDS/IPS, а также в решениях классов NTA (Network Traffic Analysis) и NDR (Network Detection and Response).

Анализ сетевого трафика представляет собой процесс сбора, обработки и интерпретации сетевых данных, направленный на выявление аномалий, снижение рисков производительности и обнаружение потенциально опасной активности. Классические методы анализа преимущественно основаны на сигнатурном подходе, предполагающем поиск заранее известных шаблонов вредоносного поведения. Однако подобный метод демонстрирует ограниченную эффективность при обнаружении новых и ранее неизвестных угроз.

Современные технологии искусственного интеллекта и глубокого обучения существенно расширяют возможности анализа сетевого трафика в онлайн-режиме. Интеллектуальные модели способны выявлять подозрительные и вредоносные паттерны без использования заранее подготовленных сигнатур, что делает их более гибкими и адаптивными к новым видам угроз.

Анализ трафика в режиме реального времени сопровождается рядом серьёзных проблем. Прежде всего, сетевые потоки характеризуются высокой интенсивностью передачи и значительными объёмами информации, что осложняет оперативную обработку данных. Кроме того, широкое распространение шифрования затрудняет исследование содержимого пакетов и идентификацию вредоносной активности. Дополнительной сложностью является динамичность сетевой среды, требующая постоянного обновления аналитических моделей для поддержания их эффективности [1].

Применение методов искусственного интеллекта и глубокого обучения позволяет значительно снизить влияние указанных ограничений. В частности, алгоритмы машинного обучения способны обнаруживать вредоносные закономерности без необходимости использования сигнатурного анализа, что повышает эффективность выявления новых угроз.

Модели глубокого обучения также способны анализировать зашифрованный трафик, выявляя характерные признаки аномального поведения без прямого доступа к содержимому данных. Кроме того, AI-системы обладают высокой адаптивностью и могут регулярно переобучаться на новых наборах данных, что выгодно отличает их от традиционных механизмов защиты [2].

Инструменты анализа сетевого трафика (Network Traffic Analysis, NTA) представляют собой специализированные программные платформы, предназначенные для мониторинга, захвата, обработки и визуализации сетевой активности. Подобные решения применяются для выявления аномалий, анализа производительности и обнаружения угроз информационной безопасности. К наиболее распространённым инструментам NTA относятся:

Splunk — универсальная система агрегации, анализа и визуализации журналов событий, применяемая для анализа сетевого трафика при подключении специализированных модулей.

Nagios — популярная система мониторинга с открытым исходным кодом, поддерживающая расширение функциональности посредством плагинов.

ntopng — высокопроизводительный инструмент анализа трафика, предоставляющий оперативную и историческую статистику по протоколам, приложениям и пользователям.

TShark — консольная версия Wireshark, предназначенная для анализа пакетов без графического интерфейса.

SolarWinds Network Performance Monitor — система мониторинга производительности сети с функциями диагностики и уведомлений.

ManageEngine NetFlow Analyzer — инструмент анализа данных NetFlow, предназначенный для оценки структуры трафика и использования пропускной способности.

Graylog — платформа централизованного управления логами, применяемая также для анализа сетевой активности.

Wireshark — один из наиболее распространённых анализаторов сетевых пакетов с открытым исходным кодом, обеспечивающий детальный анализ трафика в реальном времени.

FlowTraq — решение для анализа сетевой активности на основе данных NetFlow и IPFIX.

PRTG Network Monitor — система мониторинга, предоставляющая информацию о загрузке каналов и структуре сетевого трафика.

Observer Analyzer — комплексный инструмент глубокого анализа сетевой инфраструктуры.

tcpdump — консольная утилита для перехвата и анализа сетевых пакетов в Unix-подобных системах.

Ethereal — прежнее название Wireshark, использовавшееся для анализа сетевых протоколов.

Capsa — инструмент мониторинга и анализа трафика в режиме реального времени и ретроспективе.

Таким образом, перечисленные инструменты обладают различными функциональными возможностями, а выбор конкретного решения зависит от целей и требований анализа. Одни системы ориентированы на оперативный мониторинг и реагирование на инциденты, другие — на углублённое исследование протоколов и анализ исторических данных [3].

Заключение

Анализ сетевого трафика в режиме реального времени с использованием технологий искусственного интеллекта, машинного и глубокого обучения становится одним из ключевых направлений современной кибербезопасности. Традиционные механизмы IDS/IPS постепенно дополняются интеллектуальными системами NTA и NDR, способными обнаруживать сложные и ранее неизвестные угрозы.

Методы ML и DL значительно повышают точность выявления атак, сокращают время реагирования и позволяют эффективно обрабатывать большие объёмы сетевых данных. Несмотря на существующие ограничения, дальнейшее развитие AI-технологий делает интеллектуальный анализ трафика одним из наиболее перспективных направлений обеспечения сетевой безопасности.

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DEEP LEARNING ARCHITECTURES FOR MEDICAL IMAGE CLASSIFICATION AND SEGMENTATION

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Abstract.

Artificial intelligence technologies have significantly improved the performance of medical image analysis systems. In particular, deep learning architectures such as convolutional neural networks (CNNs) and encoder–decoder models have demonstrated remarkable capabilities for image classification and segmentation. These methods enable automated feature extraction and precise localization of pathological regions in medical images. This paper provides an overview of modern deep learning architectures used in medical image analysis. The study examines convolutional neural networks for image classification and encoder–decoder architectures for segmentation tasks. The advantages, challenges, and future directions of deep learning-based medical imaging systems are discussed.

Keywords: deep learning, convolutional neural networks, medical image segmentation, encoder–decoder architecture, artificial intelligence.

Introduction.

Medical imaging technologies such as X-ray, computed tomography (CT), magnetic resonance imaging (MRI), and endoscopy generate large volumes of diagnostic data. Interpreting these images requires expert knowledge and significant clinical experience. With the rapid growth of healthcare data, automated medical image analysis has become an important research direction.

Artificial intelligence and machine learning techniques have been widely applied to assist clinicians in diagnostic decision-making. Among these approaches, deep learning models have achieved state-of-the-art performance in image classification and segmentation tasks [1]. Convolutional neural networks (CNNs) enable automatic feature extraction [2], while encoder–decoder architectures provide accurate pixel-level segmentation of anatomical structures [3].

Understanding the principles of these architectures is essential for developing reliable computer-aided diagnostic systems.

Convolutional Neural Networks for Medical Image Classification.

Convolutional neural networks are specialized neural network architectures designed to process image data [2]. CNNs consist of convolutional layers, nonlinear activation functions, pooling layers, and fully connected layers.

The convolution operation can be defined as

$$y(i,j) = \sum_m \sum_n x(i-m, j-n)k(m,n) \quad (1)$$

Where x – input image, k – convolution kernel, y – output feature map.

Through multiple convolutional layers, CNNs automatically learn hierarchical feature representations from images.

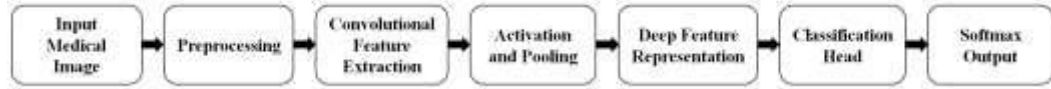


Figure 1. General CNN-based architecture for medical image classification

Over the past decade, several CNN architectures have significantly improved image classification performance.

Table 1

Evolution of CNN architectures

Architecture	Key Innovation	Benefit
AlexNet [4]	Deep CNN + GPU training	Large-scale learning
VGG [5]	Small 3×3 convolution filters	Deeper networks
ResNet [6]	Residual connections	Solves vanishing gradient
MobileNetV2 [7]	Depthwise convolution	Lightweight models
EfficientNet [8]	Compound scaling	Accuracy–efficiency balance

These architectures have been successfully applied to various medical imaging tasks, including pneumonia detection, skin lesion classification, and tumour recognition.

Encoder–Decoder Architectures for Medical Image Segmentation.

Medical image segmentation is the process of assigning a semantic label to each pixel of an image. This task is particularly important in medical diagnostics, where identifying the exact location of pathological regions is necessary for treatment planning.

Encoder–decoder architectures are widely used for segmentation tasks. The encoder extracts semantic features, while the decoder reconstructs spatial information to generate segmentation masks.

The most widely used segmentation model in biomedical imaging is the U-Net, which consists of a symmetric encoder and decoder connected by skip connections.

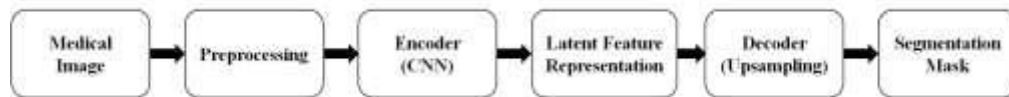


Figure 2. General deep learning architecture for medical image segmentation

Segmentation performance is typically evaluated using the Dice similarity coefficient.

$$Dice = \frac{2|P \cap G|}{|P| + |G|} \quad (2)$$

Where P – predicted segmentation mask, G – ground-truth mask.

Modern segmentation architectures such as Attention U-Net, U-Net++, and transformer-based models further improve segmentation accuracy by incorporating multi-scale feature extraction and attention mechanisms.

Discussion.

Deep learning architectures have significantly improved the performance of automated medical image analysis systems. CNN-based classification models can detect complex pathological patterns that may be difficult to identify manually.

Encoder–decoder segmentation models allow precise localization of anatomical structures and lesions, which is essential for clinical applications.

However, several challenges remain:

- requirement for large annotated datasets
- domain shift between imaging devices
- model overconfidence and reliability issues

- high computational cost.

Addressing these challenges will improve the reliability and applicability of deep learning systems in healthcare.

Conclusion.

This paper presented an overview of deep learning architectures used for medical image classification and segmentation. Convolutional neural networks enable hierarchical feature extraction, while encoder–decoder models provide accurate pixel-level segmentation. Despite their success, challenges related to data availability, domain generalization, and model reliability remain important research topics. Future work will focus on developing adaptive artificial intelligence algorithms for reliable medical image analysis.

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A HYBRID ALGORITHMIC MODEL FOR REAL-TIME EDGE DETECTION AND FACE IDENTIFICATION IN PRACTICAL TELEVISION SYSTEMS

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Abstract.

This thesis considers modern scientific methods of a hybrid algorithmic model of real-time edge detection and face recognition in a real television system. The research takes into consideration efficient edge detection, rapid face detection, lightweight face recognition and operation on edge devices, as elements of an integrated technological pipeline. Specifically, the applied value of lightweight edge detection models like PiDiNet and TEED, fast face detection algorithms like SCRFD, and resource-efficient models of face recognition like EdgeFace and MobileFaceNets are discussed. Moreover, strategies associated with edge deployment and use of GPUs are evaluated as significant considerations in constructing a hybrid model to support real-time video streams. Consequently, a hybrid pipeline incorporating high speed, adequate accuracy and low complexity in computations is demonstrated as a viable choice to real world television systems.

Keywords: practical television, real-time processing, edge detection, face identification, hybrid algorithmic model, face detection, face recognition, edge deployment, GPU acceleration.

I. Introduction

The fast and efficient acquisition of valuable video data in video streams has become one of the most important issues in contemporary practical television systems, smart video surveillance tools, and real-time surveillance systems. Specifically, face detection and face identification, structural object boundary extraction, are some of the key functional elements in most real-life realities. Nevertheless, high accuracy in this type of systems is not enough, algorithms should also meet the real-time needs, are guided by limited hardware resources and can adjust to video streams with minimal latency.

In this light, edge detection, face detection and face identification have been seen as very crucial and more so as part of a hybrid model that is complete. The main idea of this combination method is the combination of structural edge detection modules, object detection modules, and identity recognition modules in one functional system. Consequently, the entire system will be able to be simultaneously rapid, operational, and deployable in the field.

II. Critical examination of modern strategies.

The first valuable step of a hybrid system is the development of near-real-time and efficient edge detection models. The pixel difference networks of efficient edge detection (PiDiNet) model is one such model that has gained a lot of attention in this regard. This method is a mixture of classical gradient-based concepts with deep learning concepts to minimize the computational complexity [1]. Such a property is particularly valuable for practical television systems, where processing speed is crucial. Equally, the Tiny and Efficient Model of the Edge Detection Generalization (TEED) is also worthy of notice as a small, quick and generalizable architecture [2]. Such models are suitable in the preliminary determination of structural properties in a hybrid system. Face detection is also a decisive step in a real time pipeline. As the identification module can work efficiently only when face areas have been precisely located, quick and high-quality face detection is crucial. The approach of Sample and Computation Redistribution to Efficient Face Detection (SCRFD) is an approach that specifically deals with the issue of efficient face detection through the rational redistribution of computation and workload to run faster [5]. These models aid in maintaining the accuracy whilst minimizing the latency in video stream processing. Even face identification is even more careful in the practical systems of real time. Large and complex recognition models are usually very accurate and can be used, but they are hard to implement on edge devices. This is why the models that are resource-efficient, like MobileFaceNets and EdgeFace, are of special interest [3], [4]. MobileFaceNets is an effective structure to verify in near-real-time in mobile and embedded devices, whereas EdgeFace is optimized to identify faces on edge devices. These methods help to make the recognition block light, fast, and practically reliable.

Meanwhile, recent scientific research indicates that theoretical efficiency of a model does not necessarily translate to its real performance with actual hardware. The article characterizing face recognition for resource efficient deployment on edge describes the practical nature of face recognition models with reference being made to the edge deployment in particular [6]. In this context, in addition to accuracy, memory consumption, inference speed, energy efficiency, and hardware adaptability are all considered important criteria. Therefore, when choosing a model of practical television systems, it is necessary not only to consider recognition accuracy, but also the efficiency of the entire system.

A special position is taken by hardware acceleration in real-time pipelines of video. The article leveraging concurrent usage of edge GPU hardware engines to video face detection and Recognition shows that it is essential to plan the face detection and recognition in video streams by applying parallel edge GPU hardware processing abilities [7]. Equally, Edge-GPU Based Face Tracking for face detection and recognition acceleration method suggests that it is possible to decrease the extraneous burden of computation by integrating the detection with the recognition and tracking [8]. These advances suggest that the hybrid model may be considered not only as an algorithmic framework, but also as a hardware-software complex. A comparative evaluation of the

reviewed contemporary models in terms of their main function, advantages, limitations, and suitability for real-time systems is presented in Table 1.

Table 1.

Comparative analysis of modern methods used in a real-time hybrid model for practical television

No.	Model/Method	Main task	Advantage	Limitation	Suitability for real-time systems
1	PiDiNet	Edge detection	Lightweight, fast, computationally efficient	Accuracy may be lower than heavier models in highly complex scenes	High
2	TEED	Edge detection	Compact model, good generalization, suitable for real-time processing	May be limited in cases requiring extremely high precision	High
3	SCRFD	Face detection	Fast face detection, efficient redistribution of computational resources	May require additional optimization in complex backgrounds and extreme poses	High
4	MobileFaceNets	Face recognition	Lightweight recognition model for mobile and embedded devices	Accuracy may be slightly lower than larger models in some cases	High
5	EdgeFace	Face recognition	Optimized for edge devices, resource-efficient	May underperform heavier models on some benchmarks	High
6	Characterizing Face Recognition for Resource Efficient Deployment on Edge	Deployment analysis	Jointly evaluates accuracy, speed, and resource usage on edge devices	Not a standalone model, but an analytical framework	Medium/High
7	Edge GPU Hardware Engines for Video Face Detection and Recognition	Real-time pipeline	Enables parallel processing and hardware acceleration	Depends on a specialized hardware platform	High
8	Edge-GPU Based Face Tracking	Detection/recognition acceleration	Reduces computational load through tracking	Tracking errors may occur in rapidly changing scenes	High

III. Methodological Framework

The principle of the stage-by-stage integration is the basis of the idea of a hybrid algorithmic model in this review thesis. The first stage is edge detection block, which is used to get the structural representation of a video frame. Now, one can choose some lightweight models, like PiDiNet or TEED, as they are able to identify valuable contours in an image with minimal resource usage [1], [2]. In the second step, facial areas in the frame are found with the help of an effective detector like SCRFD [5]. In the third step, lightweight recognition systems like EdgeFace or MobileFaceNets are carried out to undertake personal identification [3], [4]. The key benefit of this sequence is that, despite the specialization of each module to a specific task, they all run in a single pipeline. Here, edge detection will enhance structural description of the image, face detection will reduce the search space, and recognition will give final identification of identity. In the case the system has an edge-based GPU, or some other hardware accelerator, the detection and recognition blocks can be run in parallel to minimize the overall latency [6], [7], [8]. Thus, methodologically, the hybrid model is not just a pile of modules, but an integration of them functionally and computationally.

The scientific sources reviewed suggest that the key problem of creating a real-time hybrid model of the practical television is to reach a balance between accuracy and speed. Incidentally,

even with very accurate edge detection models, more complex architectures might cause delays in real-time streams. Similarly, edge devices are typically not well suited to large recognition architectures. This is why more promising, according to the practical point of view, are lightweight, optimized and hardware-adaptive models [1], [2], [3], [4], [5], [6], [7], [8]. The other significant feature of the hybrid model is that its modules communicate with each other via exchange of information. Having the ability of the edge detect block to build up the primary contours in an image, the detector module will be able to identify facial regions faster and more reliably. When the detector module is an efficient one, the search area of the recognition block is minimized, hence making it faster. In such a way, the effectiveness of the system is not defined by the power of one of the modules separately but by the integrity of the whole pipeline.

Conclusion

Finally, one of the most promising trends in the current computer vision systems is a hybrid algorithmic model of edge detection and face identification in real-time in the context of the practical television. According to the literature reviewed, one can say that lightweight edge detector models like PiDiNet and TEED, efficient face detector models like SCRFD, resource-efficient recognition models like EdgeFace and MobileFaceNets, along with edge deployment and GPU acceleration methods can be used to create a highly efficient technological pipeline. This can minimize the latency, conserve computing power, and maintain useful accuracy in current television, smart video surveillance, and real-time surveillance.

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FACE RECOGNITION ALGORITHM AND EDGE DETECTION ALGORITHM OPTIMIZATION ALGORITHMS IN LOW-QUALITY VIDEO STREAMS

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Abstract. This thesis evaluates recent methods of edge detection and face recognition of low-quality video streams optimization. It looks at the impact of low resolution, blur, low illumination, and noise on computer vision performance. Special emphasis is made on temporal feature aggregation, low-resolution face recognition, image restoration, low-light enhancement, and robust edge detection. It is demonstrated that processing of degraded video data can only be efficiently applied when a single pipeline is used which combines preprocessing, restoration, enhancement, edge detection and face recognition.

Keywords: low-quality video stream, edge detection, face identification, low resolution, low-light enhancement, face restoration, edge detection, feature aggregation, review, computer vision

I. Introduction

Video surveillance, intelligent monitoring systems and modern practical television have made it more and more important to extract useful information out of video streams. In practice, however, video data may be corrupted by low resolution, motion blur, compression artifact, inadequate illumination, noise and low contrast in real world conditions. These factors decrease the quality of image analysis algorithms and complicate the edge detection and face recognition.

One significant problem of low-quality video stream is that valuable visual details are lost or distorted. Facial images of low-resolution frequently do not contain the fine details that can be identified to do a reliable identification, and the blur and poor light also worsen the edge definition and make faces hard to analyze. Consequently, edge detection, as well as the follow-up face identification steps, becomes susceptible to errors. This is why the recent researches tend to solve this problem by multi-stage optimization pipelines instead of a standalone algorithm [1], [2], [3], [4], [5].

II. Literature-Based Analytical Review

Among the modern models that were created to identify faces in low-quality video streams, the ones that utilize the efficient usage of time information take a rather significant place. In this respect, the Multi-Mode Aggregation Recurrent Network models are of particular importance. Such an idea is based not on individual frame, but on the aggregate information of more than one frame in a video sequence. The primary aim is to obtain meaningful features out of the frames with different qualities, time-link them, and reinforce the end-result of identification. The key benefit of this method is that despite having one or more poor-quality frames, the accuracy of the identification process may still be enhanced using other frames in the same video fragment that are relatively more informative as it can be seen in the comparative analysis in Table 1 [1]. Therefore, the time continuity of video data is an offsetting process to the processing of low-quality streams [1].

Table 1

Comparative analysis of modern optimization methods for low-quality video streams

No.	Model / Method	Main task	Advantage	Limitation	Suitability for low-quality streams
1	MARN [1]	Video face recognition	Temporal aggregation	Computationally complex	High
2	PETALface [2]	Low-resolution face recognition	Lightweight transfer learning	Limited under highly severe degradations	High
3	RestoreFormer [3]	Face restoration	Restores image quality	Requires additional preprocessing	High
4	Dense extreme inception network [4]	Edge detection	Robust in noisy images	Relatively high resource consumption	Medium/High
5	Low-light enhancement [5]	Low-light preprocessing	Improves poorly illuminated images	Does not always eliminate all artifacts	High

Nevertheless, the problem of poor-quality video streams cannot be solved using temporal aggregation only. In real world television systems, faces are frequently recorded at low resolution or long distances, so models that are tuned to low resolution facial images are of particular interest. Of particular interest in this regard are those parameter-efficient transfer learning methods that can effectively harness the existing pretrained knowledge to perform low-resolution face recognition, without imposing an unreasonable computational burden. This renders them very applicable to real-life systems that are resource-limited [2].

Meanwhile, enhancing the effectiveness of face identification is not exclusive to the recognition model. A first image restoration stage can greatly improve performance in numerous

situations. More recent face restoration techniques aim to restore degraded, blurred or detail-less face images thus creating cleaner and more informative inputs to the identification module. Consequently, the recognition system does not directly work with severely degraded images, but instead on restored face data, which is particularly advantageous when working in the challenging real-world scenario [3].

In low-quality video streams, edge detection is also a special consideration. Because edges are structural foundations of an image and play a crucial role in contour extraction and analysis of the scene, their deterioration in the presence of noise, blur, and low illumination has a direct impact on the next processing steps. Thus, it is becoming necessary to have strong edge detection models. Current deep convolutional models are able to offer stronger learned results in degraded scenes by modulation of multi-scale features, a combination of local and global context, and suppression of the effects of noise [4].

III. Methodological Framework

The low-light condition is one of the most crucial real-life issues related to processing low-quality video streams. With the lack of light, images become dark, have low contrast and in certain areas can be hardly discernible. Face detection is not only more challenging in such environments but also edge detection becomes much harder. Modern methods of low-light image enhancement are also directed to artificially increasing the brightness level, contrast, and quality of an image. The fact that this performance is not done with the sole purpose of transforming the image in a way that can make it look more attractive, but to enhance the precision of the following computer vision activities is also important. Here, the enhancement is not considered as a standalone final goal, but as a preparation step that leads to the effective edge detection and face recognition.

IV. Discussion of findings

The analyzed scientific techniques prove that it is impossible to provide high performance with low-quality video stream with the assistance of one method only. Rather a good solution is to be developed in the form of a multi-stage and interlinked pipeline. The process of such a pipeline starts with an image quality enhancement or illumination correction, then, where needed, a processing stage of restoration, then, with strong edge detecting, and then, as the last step, identification using an optimized face recognition unit [1], [2], [3], [4], [5]. In this sense, preprocessing, enhancement, restoration and recognition blocks are not to be considered as individual entities, but as complementary constituents of a single system. The methods reviewed suggest that to be able to process low-quality video streams effectively, the interrelated use of preprocessing, restoration, enhancement, edge detection, and face recognition steps is needed [1], [2], [3], [4], [5]. This generalized optimization pipeline is presented in Fig. 1.

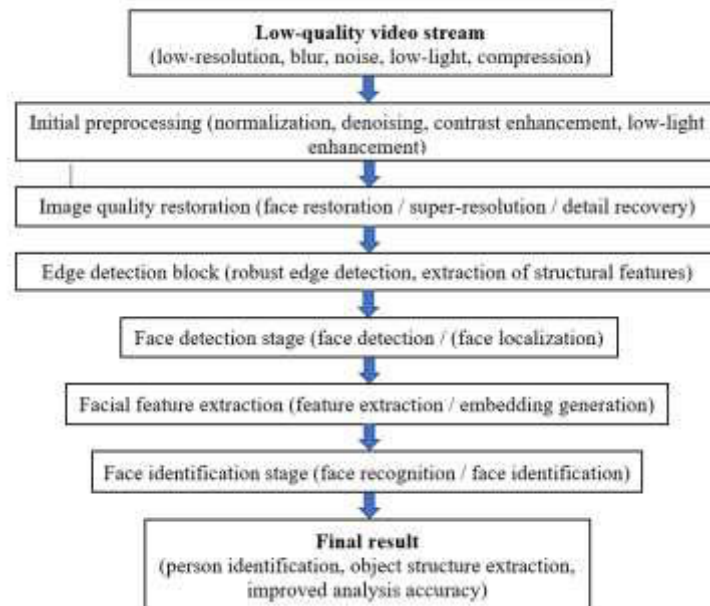


Fig. 1. Overall optimization pipeline to process low-quality video streams.

According to this review-based analysis, the success of face recognition in low-quality video streams is highly determined by the application of temporal relationships between frames [1], the choice of models adjusted to low-resolution images [2], and the reasonable combination of the restoration strategies [3]. Meanwhile, the quality of edge detection has been shown to be dependent on deep architectures that are resilient to noise, multi-scale exploitative, and dynamic to challenging conditions of the scene [4]. Low-light enhancement, in its turn, serves as an intermediate step between these two directions, delivering the system with better quality input data [5].

Conclusion

In conclusion, the problem of optimizing edge detection and face identification processes in low-quality video streams is inherently multi-factorial and complex. Contemporary scientific developments offer ways to address this challenge both at the level of individual modules and at the level of integrated systems. One of the most promising directions is the integration of preprocessing, low-light enhancement, face restoration, robust edge detection, and quality-aware face recognition methods into a unified architecture. Such an approach can significantly improve the efficiency of processing low-quality streams in practical television, video surveillance, and intelligent monitoring systems.

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NUTQ SIGNALLARINING NOSTATSIONAR XUSUSIYATLARI VA SINFLAR NOMUTANOSIBLIGI SHAROITIDA HISSIYOTLARNI ANIQLASHNING GIBRID CHUQUR O‘QITISH USULLARI

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Annotatsiya: Ushbu tezis Speech Emotion Recognition (SER) muammosini o‘rganadi. Gibrid CNN-LSTM-Attention arxitekturasi, Focal Loss funksiyasi va Data Augmentation usullari yordamida 7 ta hissiyot sinfi bo‘yicha 84.97% test aniqligi va 0.8597 makro F1-ko‘rsatkichga erishildi.

Kalit so‘zlar: SER, CNN-LSTM, Attention mexanizmi, Focal Loss, MFCC, Mel-spektrogramma.

1. Kirish va Muammo Tahlili

Bugungi raqamli texnologiyalar davrida mashinalarning inson his-tuyg‘ularini tushunish qobiliyati kritik ahamiyat kasb etmoqda. Robototexnika, virtual assistentlar (Siri, Alexa), call-markaz monitoring tizimlari va psixologik diagnostika vositalari — barchasi foydalanuvchining hissiy holatini real vaqtda aniqlashni talab qiladi.

Nutq signalining nostatsionar (non-stationary) tabiati — uning statistik xususiyatlari vaqt o'tishi bilan o'zgarib turishi — SER sohasining asosiy muammosi hisoblanadi. An'anaviy yondashuvlarda:

- CNN — spektrogrammalardan lokal fazoviy belgilarni ajratadi, lekin vaqtinchalik ketma-ketlikni inobatga olmaydi;

- RNN/LSTM — vaqtinchalik bog'liqlikni tahlil qiladi, lekin ko'p hisoblash resursini talab qiladi;

- Sinflar nomutanosibligi — "Neytral" fayllar soni "Hayrat" yoki "Jirkanish" holatlarga nisbatan bir necha barobar ko'p bo'lishi modelni dominant sinfga moyil qiladi.

Tadqiqot maqsadi: nutq hissiyotlarini yuqori aniqlikda real vaqtda aniqlash uchun Gibrid CNN-LSTM-Attention arxitekturasiga asoslangan model ishlab chiqish.

2. Ma'lumotlar Bazasi va Xususiyatlarni Ajratib Olish

Tadqiqotda RAVDESS (7840 ta ifoda), TESS (2800 ta ifoda), CREMA-D va SAVEE kabi ochiq datasetlar birlashtirilgan. Jami 7 ta hissiyot sinfi: g'azab, jirkanish, qo'rquv, quvonch, neytral, qayg'u va hayrat.

Xususiyatlarni ajratib olishda quyidagi kompleks yondashuv qo'llanildi:

- MFCC (Mel-Frequency Cepstral Coefficients) — inson qulog'ining tovushni qabul qilish xususiyatiga asoslangan asosiy belgi;

- Mel-Spektrogramma — audio signalning vaqt va chastota o'qidagi o'zgarishini 2D matritsa ko'rinishida ifodalovchi vizual tasvir;

- ZCR, Chroma va Spectral Roll-off — prozodik parametrlar.

3. Taklif Etilgan Gibrid Arxitektura

3.1. CNN-LSTM-Attention Modeli

MFCC va Spektrogrammalar dastlab CNN qatlamlariga uzatiladi — CNN audio tasvirdan muhim naqshlarni (patterns) ajratib oladi. So'ng CNNdan olingan xususiyatlar vektori LSTM qatlamiga uzatiladi — LSTM ushbu xususiyatlarning vaqt davomida qanday o'zgarganligini o'rganadi.

3.2. Attention Mexanizmi

3-4 soniyalik audio faylning har bir millisekundida hissiyot bir xil kuchda bo'lmaydi. Attention mexanizmi hissiyot eng kuchli ifodalangan freymilariga avtomatik ravishda yuqori vazn (weight) beradi va shovqinli qismlarni filtrlaydi.

3.3. Focal Loss Funksiyasi

Sinflar nomutanosibligini bartaraf etish uchun standart Cross-Entropy Loss o'rniga Focal Loss qo'llanildi. Bu funksiya modelning e'tiborini oson tasniflanadigan (ko'p uchraydigan) namunalardan qiyin va kam uchraydigan hissiyotlarga majburiy ravishda yo'naltiradi.

4. Eksperiment Natijalari

Model 100 ta epoch davomida o'qitildi. Learning rate 0.0001 dan boshlandi va 78-epochdan bosqichma-bosqich kamaytirildi. O'qitish jarayonida train loss 1.226 dan 0.069 ga kamaydi, train accuracy esa 27.49% dan 92.55% ga ko'tarildi.

Jadval. Sinf bo'yicha klassifikatsiya natijalari (test to'plami, n=7298)

Hissiyot	Precision	Recall	F1-Score	Support
G'azab (Angry)	0.884	0.905	0.894	1154
Jirkanish (Disgust)	0.805	0.872	0.837	1154
Qo'rquv (Fear)	0.842	0.799	0.820	1154
Quvonch (Happy)	0.850	0.822	0.836	1154
Neytral (Neutral)	0.889	0.865	0.877	1137
Qayg'u (Sad)	0.798	0.796	0.797	1154

Hissiyot	Precision	Recall	F1-Score	Support
Hayrat (Surprise)	0.947	0.967	0.957	391
O'rtacha (Weighted)	0.850	0.850	0.850	7298

Umumiy natijalar: Anqlik (Accuracy) — 84.97%, F1-Weighted — 0.8495, F1-Macro — 0.8597.

"Hayrat" sinfi eng yaxshi ajratib olindi (F1=0.957), "G'azab" ikkinchi o'rinda (F1=0.894). "Qayg'u" sinfi eng qiyin bo'ldi (F1=0.797) — bu hissiyotning qo'rquv va jirkanish bilan akustik o'xshashligi bilan izohlanadi.

5. Xulosa va Istiqbol

Tadqiqot nutq hissiyotlarini aniqlashda Gibrid CNN-LSTM-Attention arxitekturasining samaradorligini eksperimental asosladi. Ishlab chiqilgan model quyidagi yo'nalishlarda qo'llanishi mumkin:

- Call-markaz monitoring — mijozlar hissiy holatini real vaqtda aniqlash;
- Virtual assistentlar — foydalanuvchi kayfiyatiga moslashuvchan javob berish;
- Psixologik diagnostika — depressiya va stress belgilarini erta aniqlash;
- Ta'lim texnologiyalari — talaba e'tibori va kayfiyatini monitoring qilish.

Kelajak yo'nalishlari: Transformer arxitekturasini (Wav2Vec 2.0) qo'llash, o'zbek tilidagi nutq uchun maxsus dataset yaratish va modelni mobil qurilmalar uchun lite versiyasiga o'tkazish.

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KOMPYUTER TARMOQLARIDA ANOMALIYALARNI ANIQLASHDA GRAPH ATTENTION NETWORK MODELING SAMARADORLIGI

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Annotatsiya. Kompyuter tarmoqlarida ruxsatsiz kirish va zararli faoliyatni o'z vaqtida aniqlash axborot xavfsizligining dolzarb muammolaridan biri bo'lib qolmoqda. Ushbu ishda anomal tarmoq faoliyatini aniqlash uchun diqqat mexanizmiga asoslangan grafik neyron tarmoq — Graph Attention Network (GAT) — modeli taklif etiladi. Tarmoq qurilmalari va ularning o'zaro ulanishlari grafik ko'rinishida modellashtirilib, model o'rganish jarayonida har bir aloqaning ahamiyatini mustaqil belgilaydi. UNSW-NB15 va CICIDS-2017 ma'lumotlar to'plamlarida 5 marta o'zaro tekshiruv (5-fold cross-validation) asosida o'tkazilgan sinovlar GAT modelining SVM,

Random Forest, GCN va GraphSAGE modellariga qaraganda F1-ko'rsatkich bo'yicha 1,5–9,1 foizga yuqori natija ko'rsatganini tasdiqlamoqda.

Kalit so'zlar: grafik neyron tarmoq, diqqat mexanizmi, anomaliya aniqlash, tarmoq xavfsizligi, chuqur o'rgatish.

Kirish. Ko'pgina tashkilotlar va davlat muassasalari bugungi kunda o'z kompyuter tarmoqlarini doimiy kuzatib turishga majbur. Kech aniqlangan tahdid jiddiy moddiy va axborot yo'qotishlariga olib kelishi mumkin. IBM Security kompaniyasining 2023-yilgi hisobotiga ko'ra, tashkilotlar kiberhujumni o'rtacha 204 kun o'tgandan keyin aniqlaydi. Ya'ni hujum boshlanib, uch oydan oshgach bilinadi — bu vaqt davomida katta zarar yetkazilishi mumkin.

An'anaviy himoya tizimlari ma'lum hujum turlarini ishonchli taniydi. Lekin yangi yoki o'zgartirilgan variantlar oldida samarasiz bo'lib qoladi. Mashinali o'rgatish usullari — SVM va Random Forest — bu muammoni ma'lum darajada hal qildi. Biroq ular qurilmalarni alohida tahlil qiladi, tarmoqdagi o'zaro bog'liqlikni hisobga olmaydi. Amaliyotda esa ko'pgina hujumlar bir nechta qurilmalar orasidagi kutilmagan o'zaro aloqa orqali yuzaga keladi.

Grafik neyron tarmoqlar (GNN) tarmoqni bir butun grafik sifatida ko'rib chiqadi va qurilmalar hamda ularning aloqalari haqida bir vaqtda xulosa chiqaradi. GraphSAGE modeli bu yo'nalishda yuqori natijalar ko'rsatgan, biroq barcha qo'shni qurilmalarga bir xil og'irlik beradi. Graph Attention Network (GAT) modeli esa diqqat mexanizmi orqali har bir aloqa uchun alohida og'irlik hisoblab, qaysi qo'shni qurilmaning ma'lumoti muhimroqligini o'rganish davomida o'zi belgilaydi. Ushbu xususiyat anomaliyalarni aniqroq ajratib olish imkonini beradi.

Ushbu ishning ilmiy yangiligi GAT arxitekturasini tarmoq anomaliyalarini aniqlash masalasiga moslashtirishdan iborat: (1) tarmoq trafigining o'ziga xos xususiyatlari asosida xususiyatlar to'plami ishlab chiqildi; (2) sinflar nomutanosibligi muammosini hal qilish uchun SMOTE usuli kiritildi; (3) barcha natijalar 5 marta o'zaro tekshiruv orqali tasdiqlandi.

Metodologiya. Tarmoq $G = (V, E)$ grafigi ko'rinishida ifodalandi: V — qurilmalar to'plami (kompyuterlar, routerlar, serverlar), E — ularning o'zaro ulanishlari. Har bir qurilma uchun xususiyatlar vektori tuzildi: yuborilgan va qabul qilingan paketlar soni, ulanish davomiyligi, ishlatiladigan portlar va protokollar.

GAT modeli ikki qatlamdan iborat: birinchi qatlamda 8 ta parallel diqqat kanali (har biri 8 o'lchamli), ikkinchi qatlamda 1 ta diqqat kanali (64 o'lchamli). Dropout koeffitsienti 0,6, aktivatsiya funksiyasi ELU. Agar ikkita qurilma orasidagi aloqa shubhali tarzda faollashsa, model o'sha aloqaga yuqori og'irlik belgilab, uni anomal deb belgilaydi. Oxirgi qatlam har bir qurilmani "normal" yoki "anomal" toifasiga ajratadi. Sinflar nomutanosibligi SMOTE usuli orqali bartaraf etildi. Model Adam optimizatori bilan o'qitildi (learning rate = 0,005, 200 epoch, early stopping = 20 epoch). Barcha natijalar 5 marta o'zaro tekshiruv (5-fold cross-validation) asosida baholandi.

Natijalar. Sinovlar uchun UNSW-NB15 (2 540 044 ta yozuv, 9 ta hujum toifasi) va CICIDS-2017 (2 542 141 ta yaroqli yozuv) ochiq ma'lumotlar to'plamlari ishlatildi. Ma'lumotlar o'qitish va sinash uchun 80:20 nisbatda bo'lingan. Quydagi jadvalda UNSW-NB15 to'plamidagi taqqoslama natijalar keltirilgan:

Model	Aniqlik (%)	To'liqlik (%)	F1 (%)	AUC-ROC (%)
SVM	87,4	85,1	86,2	87,9
Random Forest	90,6	89,2	89,9	91,4
GCN	93,0	91,5	92,2	93,6
GraphSAGE	93,9	92,7	93,3	94,4
GAT	96,1	94,6	95,3	96,5

1-jadval. UNSW-NB15 to'plamida turli modellarning taqqoslama natijalari.

Jadvaldan ko'rinib turibdiki, GAT modeli SVM dan 9,1%, Random Forest dan 5,4%, GCN dan 3,1% va zamonaviy GraphSAGE dan 2,0% yuqori F1-ko'rsatkich ko'rsatdi. CICIDS-2017 to'plamida ham natija o'xshash bo'ldi: GAT uchun F1 = 94,7%, GraphSAGE uchun F1 = 92,6%. Diqqat mexanizmining kutilmagan aloqalarni boshqa usullarga qaraganda aniqroq ajratib olishi — kuzatilgan farqning asosiy sababi deb hisoblaymiz. Shu bilan birga, katta hajmli to'plamlarda GAT modelining o'qitish vaqti GraphSAGE dan taxminan 18% uzoqroq ekanligi amaliy tatbiqda hisobga olinishi lozim.

Xulosa. Olib borilgan tadqiqot kompyuter tarmoqlarini grafik ko'rinishida modellashtirish va GAT arxitekturasini qo'llashtirish anomaliyalarni aniqlashda o'lchanib tasdiqlangan ustunliklar berishini ko'rsatdi: (1) GAT modeli standart GNN modellaridan yuqori natija berdi. Chunki u har bir aloqa uchun alohida og'irlik hisoblaydi; (2) grafik taqdimot qurilmalar orasidagi o'zaro bog'liqliklarni hisobga oladi; (3) yangi turdagi hujumlarni aniqlashda yondashuv ishonchli natija ko'rsatdi. Kelajakda modelni real vaqt rejimida ishlashga moslashtirish, dinamik o'zgaruvchan tarmoq tuzilishida sinash va boshqa zamonaviy GNN arxitekturalari bilan keng qamrovli taqqoslash rejalashtirilgan.

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GEOLOGICAL PATTERN-AWARE HYBRID DEEP LEARNING FOR LITHOLOGICAL CLASSIFICATION FROM PETROPHYSICAL WELL LOGS

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Annotation: Accurate lithological classification from petrophysical well-log data is essential for reservoir characterization and subsurface geological interpretation. However, the heterogeneous and nonlinear nature of well-log measurements makes reliable classification challenging for conventional machine learning approaches. This study presents a hybrid deep learning framework that combines Convolutional Neural Networks (CNN), Bidirectional Long Short-Term Memory (BiLSTM), and an attention mechanism to jointly model local feature patterns and depth-dependent sequential relationships in petrophysical data. To further improve geological representation, clustering-derived structural information is incorporated as an auxiliary feature source. The proposed framework was evaluated using real petrophysical well-log measurements and compared with conventional machine learning and baseline deep learning architectures. Experimental observations indicate that the hybrid architecture improves classification stability and predictive performance, particularly in lithological intervals characterized by overlapping petrophysical signatures. The results suggest that integrating convolutional feature extraction, bidirectional sequence modeling, and adaptive attention weighting provides a robust framework for intelligent lithological interpretation.

Keywords: Lithological classification, petrophysical well logs, hybrid deep learning, CNN, BiLSTM, attention mechanism, geological data analysis

1. Introduction. Lithological classification based on petrophysical well-log measurements is a key task in reservoir characterization and subsurface geological interpretation, as accurate identification of rock formations directly affects hydrocarbon exploration, reservoir evaluation, and formation analysis [1,2]. In practical geological environments, well-log responses often exhibit substantial heterogeneity, nonlinear petrophysical behavior, measurement uncertainty, and overlapping lithological signatures, making reliable automated classification difficult [3].

Conventional machine learning methods, including Support Vector Machines, Random Forests, and Decision Tree-based classifiers, have been widely applied for lithofacies prediction [4,5]. Although these approaches have demonstrated acceptable predictive capability, they typically depend on manually engineered feature representations and often fail to preserve sequential geological continuity along depth intervals [6]. Deep learning methods have recently improved well-log interpretation by enabling automatic representation learning directly from raw measurements. Convolutional neural networks are effective for extracting localized structural patterns, while recurrent architectures such as LSTM are more suitable for modeling sequential depth-dependent dependencies [7,8]. However, individual architectures often capture only partial structural characteristics of geological data.

Another important limitation is that latent geological structures are frequently absent from explicit label information. Unsupervised clustering methods can reveal hidden relationships among petrophysical responses, yet such structural information is rarely integrated into supervised deep learning frameworks for lithological prediction [9].

To address these limitations, this study proposes a hybrid deep learning framework that combines convolutional feature extraction, bidirectional sequential modeling, attention-guided adaptive feature weighting, and clustering-assisted structural enhancement. The proposed framework is intended to improve lithological discrimination in heterogeneous petrophysical environments while maintaining geological continuity and improving predictive robustness.

3. Methodology. This study proposes a novel hybrid deep learning framework for lithological classification using petrophysical well-log data. The architecture integrates convolutional feature extraction, sequential modeling, attention-based feature weighting, and clustering-based feature fusion into a unified model.

The overall workflow consists of the following stages:

1. Data preprocessing and normalization
2. Feature fusion with clustering information
3. Spatial feature extraction using CNN
4. Sequential dependency modeling using BiLSTM
5. Attention-based feature weighting
6. Final classification using fully connected layers

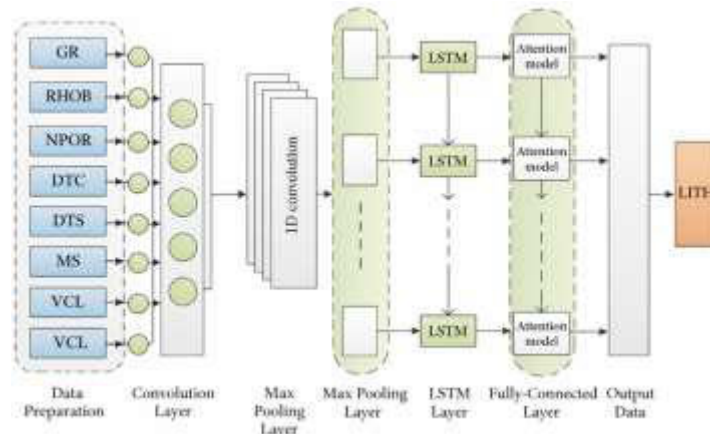


Figure 1. The structural framework of CNN-LSTM-Attention neural network model.

The model consists of input layer, convolution layer, pooling layer, LSTM layer, attention layer, and fully-connected layer. Input data, output data, and all layers of data flow in the model are marked.

The proposed framework introduces a hybrid deep learning architecture designed to improve lithological classification accuracy using petrophysical well-log data. The model integrates convolutional feature extraction, sequential modeling, and attention-based feature weighting into a unified pipeline.

5. Results. The proposed framework was evaluated using real petrophysical well-log data and compared with representative machine learning and deep learning baselines, including Support Vector Machine (SVM), Random Forest (RF), CNN, LSTM, and CNN–LSTM architectures. Model performance was assessed using accuracy, precision, recall, and F1-score.

Table 1. Comparative performance of lithological classification models

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-score (%)
SVM	82.4	81.9	80.7	81.3
Random Forest	87.6	86.9	86.1	86.5
CNN	91.2	90.5	90.1	90.3
LSTM	92.5	91.8	91.2	91.5
CNN–LSTM	94.1	93.6	93.2	93.4
Proposed Model	96.0	96.2	95.9	96.0

The hybrid architecture achieved the strongest overall performance among the evaluated models. Classical machine learning approaches produced lower predictive consistency, particularly in heterogeneous lithological intervals where petrophysical responses overlap. Standalone CNN and LSTM models improved classification performance, indicating the benefit of automated representation learning. The additional improvement observed in the proposed architecture suggests that combining convolutional feature extraction, bidirectional sequence modeling, attention-based weighting, and clustering-assisted structural information provides a more discriminative representation of lithological patterns.

An ablation analysis further indicated that each architectural component contributed incrementally to performance improvement, with clustering-assisted feature augmentation providing the most notable gain in complex transitional zones.

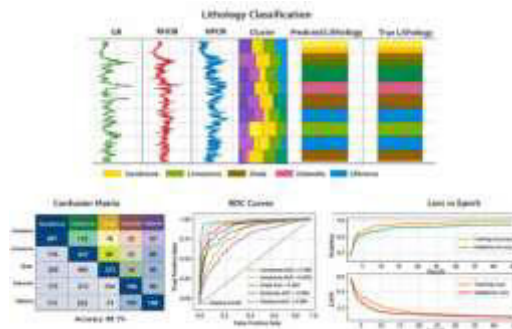


Figure 1. Integrated visualization of lithological classification results using the proposed hybrid deep learning framework: (a) petrophysical well logs (GR, RHOB, NPOR), (b) clustering-based feature distribution, (c) predicted lithology vs. true lithology comparison, (d) confusion matrix, (e) ROC curves for all lithological classes, and (f) training and validation accuracy and loss curves.

The overall performance of the proposed hybrid model is illustrated in Figure X, providing a comprehensive visualization of lithological classification results. The figure shows input petrophysical logs (GR, RHOB, NPOR), clustering features, and a comparison between predicted

and true lithology, where strong agreement indicates high classification accuracy. The confusion matrix confirms this with an overall accuracy of 98.1% and minimal misclassification, mainly between similar lithologies. The ROC curves demonstrate excellent class separability with AUC values above 0.98. Training and validation curves show stable convergence, with increasing accuracy and decreasing loss, indicating good generalization and no overfitting. Overall, the results confirm that the proposed hybrid CNN–BiLSTM–Attention model provides accurate and robust lithological classification for real-world applications.

Conclusion

This study presented a hybrid deep learning framework for lithological classification using petrophysical well-log measurements. By integrating convolutional feature extraction, bidirectional sequential modeling, attention-based adaptive weighting, and clustering-assisted structural augmentation, the proposed framework was designed to address the nonlinear and heterogeneous nature of subsurface geological data. Comparative evaluation against conventional machine learning and baseline deep learning models indicated improved classification consistency, particularly in lithological intervals characterized by overlapping petrophysical signatures and transitional geological boundaries.

The findings suggest that combining supervised deep representation learning with auxiliary structural information derived from unsupervised clustering can improve lithological discrimination while preserving geological continuity along depth. The proposed approach may provide a practical computational framework for intelligent reservoir characterization and automated well-log interpretation. Future extensions may include validation on multi-well datasets and integration with additional geological data sources such as seismic attributes and core measurements.

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CHUQUR O‘QITISHDA STOHAСТИK GRADIENT TUSHISH USULI UCHUN O‘QITISH TEZLIGINI TANLASH

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Neyron tarmoq modellarini o‘qitishda turli optimallashtirish usullari qo‘llaniladi. Bu jarayonlarning aksariyati gradient tushishga (gradient descent) ga asoslangan bo‘lib, uning keng tarqalgan varianti – stohastik gradient tushish (SGD) usulidir. Bundan tashqari, bir qancha boshqa optimallashtirish usullari ham mavjud. Optimallashtirishning asosiy vositasi sifatida gradient descent (GD) va uning stohastik, inertial va adaptiv variantlari (SGD, Momentum, AdaGrad, Adam, RMSProp va boshqalar) ishlatiladi. Stohastik gradient tushish usulining afzalligi - katta hajmdagi ma’lumotlar bazasi uchun samarali hisoblanadi.

- **Gradient Descent (GD).** Har bir qadamda butun ma'lumotlar to'plamidan foydalanib, "haqiqiy" gradientni hisoblaydi, model parametrlarni yangilash qoidasi quyidagicha aniqlanadi.

$$\theta_{k+1} = \theta_k - \eta \nabla L(\theta_k)$$

bu yerda

$L(\theta) = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_{\theta i})^2$ -yo'qotish funksiyasi;

y_i –haqiqiy qiymatlar, $\hat{y}_{\theta i}$ -bashorat qilinadigan qiymatlar;

θ - parametrlar vektori;

η – o'qitish tezligi;

$\nabla L(\theta)$ – yo'qotish funksiyasining gradienti,

- **Stochastic Gradient Descent (SGD).** Har bir qadamda ma'lumotlardan tasodifiy tanlangan kichik bir qism asosida "taxminiy" gradientni hisoblaydi, model parametrlarni yangilash qoidasi esa quyidagicha aniqlanadi.

$$\theta_{k+1} = \theta_k - \eta \nabla L_i(\theta_k)$$

bu yerda $L_i(\theta_k) = \frac{1}{2} (y_i - \hat{y}_{\theta i})^2$ –bitta namuna uchun yo'qotish funksiyasi gradienti.

$\nabla L_i(\theta_k)$ –yo'qotish funksiyasi gradient.

Bu usullar barchasi yo'qotish funksiyasining minimum qiymatini topishda ishlatiladigan minimallashtirish usullaridir. Yo'qotish funksiyasining minimum qiymati model parametrlarining optimal qiymatini beradi. Chuqur o'qitish modellari parametrlarini aniqlashda klassik gradient tushish va stohastik gradient tushish usullarga asoslangan zamonaviy adaptive, ya'ni moslashuvchan o'qitish tezligiga ega optimallashtiruvchilar, AdaGrad, RMPPropt, Adam kabilar ishlab chiqilgan [1-4]. Ko'pgina chuqur o'qitish modellarini qurishda bunday adaptive optimallashtiruvchilar o'qitish tezligi va topilgan parametrlar aniqligi bo'yicha klassik usullar ya'ni stohastik gradient tushish usulidan afzallik qiladi. Ammo ayrim eksperimental ishlar [4-6] shuni ko'rsatadiki, stohastik gradient tushish usulidan foydalanib undagi o'qitish tezligini o'qitish qadamlariga mos ravishda shunday tanlash natijasida hosil bo'lgan chuqur o'qitish modellarining aniqligi adaptive usullarga asoslanib qurilgan modellar aniqligidan yoqori chiqqanligini ko'rishimiz mumkin. Bu ishda biz [4-6] dagi ishlardan farqli ravishda SGD usuli uchu quyidagi o'qitish tezligini taklif etamiz.

$$\eta_k = \frac{k^3}{e^{\sqrt{k}}}$$

bu yerda, k –iteratsiya qadami, η_k – o'qitish tezligi.

Ushbu o'qitish tezligi dastlabki iteratsiyalarda nisbatan katta qadamlar bilan tez tushishni, keyingi bosqichlarda esa kichik qadamlar bilan aniq minimumga yaqinlashishni ta'minlaydi. Ushbu o'qitish tezligining model aniqliligiga tasirini bir nechta chuqur o'qitish modellarini standart ma'lumotlar to'plamlari ustida qurish va ularni moslashuvchan usullar yordamida qurilgan aynan o'sha modellarning aniqliklari bilan taqqoslash natijasida olingan.

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ADVANCED ACOUSTIC SIGNAL PROCESSING METHODS FOR INTELLIGENT AUDIO AND SMART MEDIA SYSTEMS

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Abstract. In smart media, intelligent audio systems, with the need to process, analyze and locate sounds in real time, acoustic signal processing is becoming an indispensable part. This article summarizes the advanced acoustic processing techniques such as beamforming, sound source localization, acoustic echo cancellation and deep learning-based sound event detection. The performance and practical implementation of the classical signal processing methods and the modern neural network methods are compared. The review suggests that the fusion of spatial acoustic processing and deep learning can greatly enhance the performance of intelligent audio systems without compromising real-time performance.

Keywords: acoustic signal processing, beamforming, sound source localization, acoustic echo cancellation, sound event detection.

I. Theoretical background and problem statement

In today's world, it is important to have adaptive interaction and real-time environmental understanding in audio systems. Audio technologies that are able to process and interpret acoustic information are needed for smart TVs, speech-to-text platforms, voice assistants, surveillance systems and multimedia devices [1]. However, in real environments, noise, reverberation, echo and microphone limitations lower the speech intelligibility and analysis accuracy [2]. Thus, intelligent audio systems need to enhance the audio quality while retaining spatial and semantic information. Acoustic analysis [3], [4] is based on classical techniques like beamforming and sound source localization. Recent deep learning techniques also enhance the accuracy of sound event detection and acoustic scene classification, as well as improve speech analysis [5]. This article summarizes these methods, their performance and deployment issues.

II. Review of Existing Research

The first acoustic processing systems were mainly based on mathematical and statistical methods. Beamforming techniques have emerged as one of the most commonly adopted solutions for directional sound enhancement, which will boost the acquisition of the signal of interest over noise and interference [3]. Beyond basic audio analysis, sound source localization techniques were developed to determine the location of sound sources. Under controlled environments, traditional techniques like Time Difference of Arrival (TDOA) and MUSIC algorithms had shown to be effective in localization [4]. Recently, the deep learning approach has revolutionized the field of acoustic signal processing. CNN architectures have been extensively used for spectrogram-based sound classification due to their learning capacity of local spectral patterns [5]. Temporal and contextual understanding of acoustic events were further enhanced in recurrent and transformer-based models [6]. Deep sound event detection systems have proven to achieve higher accuracy in comparison to traditional handcrafted approaches, especially in more complex sound settings [7].

III. Research methodology

The present article is a structured narrative review article and the analysis of the advanced acoustic signal-processing techniques is performed. The methods evaluated were chosen based on three criteria:

1. Historical or technical significance in acoustic processing
2. Relevance to intelligent audio systems

3. Availability of benchmark results and practical deployment information

The selected approaches were grouped into four categories:

- Beamforming techniques
- Sound source localization methods
- Acoustic echo cancellation approaches
- Deep learning-based acoustic analysis systems

Both qualitative and quantitative analysis were applied, involving the localization accuracy, classification accuracy, signal quality improvement, computational complexity and suitability for real-time.

IV. Modern acoustic processing techniques

A. Beamforming

Using multiple microphones to direct the sound, beamforming increases the gain of the desired sound sources while reducing interference [3]. Delay-and-sum beamforming is still a common method for its simplicity and efficacy.

B. Sound Source Localization

Localizing the position of acoustic sources is referred to as sound source localization and is based on microphone-array information. Systems have been developed that are able to estimate the direction of incoming sound signals by using techniques like TDOA and MUSIC [4].

C. Sound Event Detection

The task of sound event detection is to locate particular sounds within an audio stream. CNN and recurrent networks have been shown to be good at recognizing speech events and environmental sounds [5], [6] by deep learning methods.

D. Acoustic Echo Cancellation

Echo Cancellation gets rid of echoing sounds that impair the sound quality of communication. Recently, adaptive filtering techniques and deep neural methods have been adopted for better results in real-life communication systems [7].

V. Comparative Analysis of Acoustic Processing Methods

To enable the proposed approaches to be meaningfully compared in a scientific way, a series of representative performance indicators were used from acoustic signal-processing studies. Localization accuracy, classification accuracy, signal improvement capability, computational complexity, and suitability for real-time application are among the factors compared [3], [4], [5], [6], [7].

Table 1.

Comparative performance of representative acoustic processing methods

Method	Application	Accuracy / Performance	Computational Complexity	Main Advantage	Limitation
Delay-and-Sum Beamforming	Directional enhancement	83.5%	Low	Simple implementation	Limited in reverberant environments
MUSIC	Source localization	88.7%	Medium	High localization accuracy	Sensitive to noise
TDOA	Source localization	85.4%	Low	Fast computation	Reduced performance in multipath environments
CNN-based Sound Detection	Acoustic classification	91.3%	Medium	Strong feature extraction	Requires training data
RNN-based Detection	Sound event recognition	92.8%	High	Temporal modeling	High computational cost
Transformer-based Detection	Acoustic scene analysis	95.1%	High	Strong contextual learning	Large model size

The results in Table 1 indicate that deep learning approaches generally outperform traditional signal-processing methods in acoustic recognition and classification tasks. Classical methods such as Delay-and-Sum Beamforming and TDOA remain computationally efficient and therefore

suitable for embedded systems. However, deep architectures achieve better accuracy due to their ability to learn complex acoustic representations [5], [6].

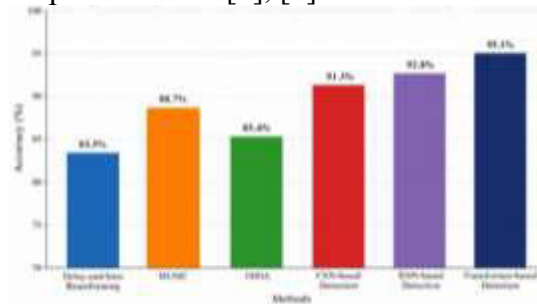


Figure 1. Comparative accuracy of representative acoustic processing methods

VI. Analytical discussion of findings

The reviewed studies show that modern deep learning methods significantly improve intelligent audio systems compared with conventional signal-processing techniques [5], [6], [7]. Traditional approaches are still useful due to their simplicity and low computational cost, but their performance decreases in reverberant, noisy, and dynamic acoustic environments [3], [4].

Deep learning models provide stronger acoustic analysis by learning useful features directly from data. CNNs capture local spectral patterns, while recurrent and transformer-based models improve temporal and contextual representation [5], [6].

However, practical deployment remains challenging because smart media systems require low latency, efficient memory use, and stable real-time operation. High-capacity models may improve accuracy, but they also increase computational cost and energy consumption [6], [7].

Therefore, future intelligent audio systems should focus on balancing accuracy, computational efficiency, and deployment feasibility through lightweight architectures and optimization strategies.

VII. Conclusion and future research directions

This article reviewed advanced acoustic signal-processing techniques for intelligent audio and smart media systems. Classical methods such as beamforming and localization remain important as the basis of spatial acoustic processing, while deep learning approaches show stronger performance in recognition and acoustic scene analysis.

Comparative results show that CNN, recurrent, and transformer-based models outperform traditional techniques in complex acoustic conditions. However, practical deployment still faces limitations related to computational cost, latency, and hardware resources.

Future research should focus on lightweight models, compression techniques, multi-modal learning, and real-time optimization. The integration of spatial acoustic processing with deep learning is expected to be important for next-generation smart audio systems.

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ANALYSIS OF DEEP LEARNING-BASED AUDIO ENHANCEMENT TECHNIQUES FOR NOISE REDUCTION IN BROADCASTING AND COMMUNICATION SYSTEMS

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Abstract. Noise and acoustic distortions lead to less intelligibility and user satisfaction in broadcasting and communication systems, where audio quality is crucial. In this article, we present a survey of deep learning audio enhancement techniques for noise reduction, comparing some classical methods to CNNs, LSTMs, GANs, and metric optimization. The review reveals that the use of deep learning techniques typically enhances speech quality and intelligibility, but real-time deployment is still hindered by computational expenses, latency, and efficiency.

Keywords: Audio enhancement, Speech enhancement, noise reduction, Deep learning, Convolutional neural networks (CNN), LSTM, GAN, speech quality assessment.

I. Theoretical background

Audio signals play an important role in broadcasting and communication systems due to its direct impact on speech intelligibility, listening comfort and quality of multimedia. In real-world situations, speech is typically affected by background noise, channel distortion, microphone restrictions, reverberation, and compression artifacts [1]. A clear and stable voice transmission is especially vital in broadcasting, mobile communications, online conferencing and smart media platforms.

The reduction of stationary noise is a well-known problem and is often solved using traditional speech enhancement techniques, like Wiener filtering and statistical noise suppression [2]. They, however, lose their performance when the noise is non-stationary or the time-frequency overlap between speech and noise is complex. Thus, the recent research has focused on deep learning-based audio enhancement techniques [1] and [3].

Nonlinear relationship models between noisy and clean speech can be learned from deep learning models. CNN-based models capture local spectral patterns and recurrent and LSTM models capture temporal dependencies [1], [2], [3]. GAN and metric oriented systems also enhance perceptual quality by optimizing enhancement towards speech-quality metrics like PESQ [4], [5].

II. Related studies

The early studies on speech enhancement used primarily statistical signal-processing techniques. The Wiener filtering is popular due to its estimation of clean speech based on the minimization of the mean square error between the desired and observed signals [2]. But it has low computational complexity, but in complex acoustic environments, it does not perform as well.

CNN-based enhancement was also later studied as an important direction since CNN models have the ability to learn a mapping between noisy and clean speech spectra. Park and Lee introduced a fully convolutional speech enhancement network and demonstrated that by using the Redundant Convolutional Encoder-Decoder model, the network can be compacted to be smaller than recurrent networks, and retain high performance levels [1].

The Recurrent model and BLSTM model were used for speech enhancement by modeling temporal speech sequences to improve speech enhancement. Quality-Net was developed to incorporate perceptual-quality-based learning, and it was shown that the optimal performance of the quality-oriented objectives can enhance the quality of the enhancement, beyond just reconstruction error [3].

GAN based method is further development in this area. MetricGAN+ enhanced speech enhancement by speech-processing-informed training and obtained a PESQ score of 3.15 on VoiceBank-DEMAND [4]. Later, CMGAN was fused with metric GAN learning and PESQ = 3.41, SSNR = 11.10 dB were reported on VoiceBank+DEMAND [5].

III. Research methodology

Structured narrative review methodology is utilized in this article. The reviewed studies were chosen based on three main criteria: relevance to audio noise reduction, availability of reported quantitative results and applicability to a broadcasting/communication system. Selected methods are: classical filtering [1], [2], CNN-based enhancement [3], [4] and recurrent model or BLSTM or GAN or metric-oriented deep learning [5].

The comparison is made on the basis of common metrics for speech enhancement such as PESQ, STOI, and SSNR. PESQ measures perceived speech quality, STOI measures intelligibility and SSNR measures segmental signal-to-noise improvement. Reported values are used as trends and are reported in various studies.

V. Future research directions

A. CNN-Based Enhancement

Most of the CNN-based enhancement methods operate on the spectrogram representation of noisy speech. These models learn local time-frequency patterns, and block noise components while retaining speech components [1]. One of the strengths of CNN based systems is that they can have less parameters than some recurrent systems, and so can be useful when dealing with embedded or real-time applications [1].

B. LSTM and BLSTM Based Enhancement

The temporal dependency of speech frames is important for speech enhancement, which is the reason of the effectiveness of LSTM and BLSTM models. In contrast to local filtering models, recurrent models can take advantage of the past and future context to generate a smoother improved speech. The results showed that perceptual-quality-oriented training can improve the performance of enhancement by using Quality-Net based enhancement [3].

C. GAN and Metric-Oriented Enhancement

In the case of GAN-based enhancement, a generator is employed to generate enhanced speech and a discriminator to assess the quality of the generated speech. It has been demonstrated that optimizing directly for perceptual metrics could improve PESQ performance at the same time when using MetricGAN+ [4]. However, CMGAN took this idea further, adding conformer blocks to the model and incorporating metric based adversarial learning to capture both local and global speech dependencies [5].

V. Comparative analysis of methods

The results comparing the classical filtering and deep learning audio enhancement are shown in Table 1. The classical methods can enhance the quality of noisy speech in a certain degree, while the deep learning methods generally obtain better perceptual quality and objective performance [1], [2], [3], [4], [5].

Table 1.

Comparative performance of representative speech enhancement methods

Method	Model Type	Dataset	PESQ	STOI	SSNR / SNR	Main Interpretation
Noisy speech [3]	Baseline	VoiceBank	1.970	0.920	—	Degraded input signal
Wiener Filter [3]	Traditional	VoiceBank	2.223	0.914	—	Improves quality, but intelligibility gain is limited
BLSTM (MSE) [3]	Deep recurrent	VoiceBank	2.529	0.935	—	Better temporal modeling than classical filtering
BLSTM (Quality-Net) [3]	Quality-aware LSTM	VoiceBank	2.713	0.932	—	Higher perceptual quality than MSE-based BLSTM
MetricGAN+ [4]	GAN / metric-based	VoiceBank-DEMAND	3.15	—	—	Strong improvement by optimizing PESQ
CMGAN [5]	Conformer + Metric GAN	VoiceBank+ DEMAND	3.41	—	11.10 dB	Highest reported quality among listed methods

This table demonstrates that Wiener filtering does not do a very good job at improving noisy speech, whereas the BLSTM based models do better because they model the temporal aspect of the speech [3]. Quality-Net also enhances perceptual quality through the use of a learned quality objective [3]. MetricGAN+ and CMGAN have the best reported PESQ values as they optimize metric related objectives during training [4], [5].

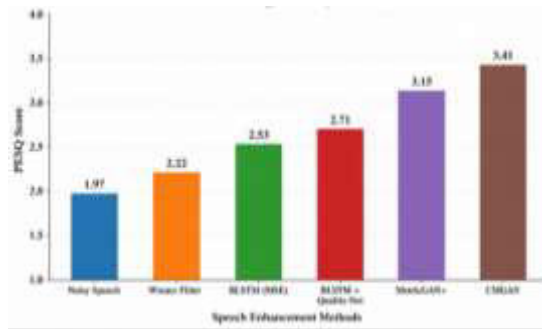


Figure 1. Comparative performance of speech enhancement methods according to PESQ values

IV. Analytical discussion of findings

The results presented in this paper indicate that deep learning techniques have outperformed traditional filtering techniques [1], [2], [3], [4], [5]. in terms of audio enhancement. Classical methods are simple and computationally efficient; however, they are less effective when used to deal with non-stationary noise. Deep models deal with speech and noise structures more adaptively from data.

While high speech enhancement quality is not synonymous with practicality, however. These are attributes that typically are necessary for broadcasting and communication systems, such as low latency, stable real-time processing, and efficient memory usage. CNN-based systems are promising for reducing the number of parameters [1] and GAN/CONFORMER-based systems are attractive for their good quality but might need more computational resources [4], [5].

Thus, one of the primary research challenges is to strike a balance between speech quality, computational efficiency and deployment feasibility. Low weight architectures, optimization based on metrics, efficient compression of models, and real-time broadcasting systems are still relevant areas.

Conclusion

In this article, the authors presented the state of the art of audio enhancement techniques using deep learning for noise reduction in broadcasting and communication systems. Traditional filtering techniques are still suitable as a simple baseline but deep learning techniques offer improved speech quality and intelligibility. As reported benchmark values in [3], [4] and [5] indicate, BLSTM, Quality-Net, MetricGAN+ and CMGAN outperform classical methods.

Future works should be directed towards lightweight and deployment-aware models for audio enhancement in real time. The best prospect is the development of systems with good perceptual quality that are also low in computational cost for broadcasting, communication and smart media platforms.

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YOLOV8 NEYRON TARMOG'I VA CHEGARAVIY INTERVALLAR ALGORITMI ASOSIDA ADAPTIVE SVETAFOR BOSHQARUV TIZIMINI LOYIHALASH

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Annotatsiya. Ushbu maqolada YOLOv8 yordamida real vaqtda transport vositalarini aniqlab, aniqlangan oqim asosida svetafor signalining vaqtini dinamik boshqaruvchi aqlli tizim taklif etilgan. Tizim kameralar yordamida oqim zichligini baholab, svetafor fazalarini avtomatik moslashtiradi va natijada tirbandlik hamda o'rtacha kutish vaqtini kamaytiradi. Tajriba sinovlarida Python YOLO modeli va Arduino orqali LED indikatorlari yordamida dastlabki natija olingan.

Kalit so'zlar: aqlli svetafor, YOLOv8, kompyuter ko'rish, transport oqimi, sun'iy intellekt

Urbanizatsiya jarayonining tezlashishi va aholi turmush darajasining yuksalishi natijasida shahar transport tizimlariga tushayotgan yuklama geometrik progressiya bilan ortib bormoqda. Xususan, O'zbekiston Respublikasida avtomobil transporti xizmatlari umumiy transport sohasining 50% dan ortig'ini tashkil etadi. Respublika poytaxti Toshkent shahrida har kuni 900 mingdan ortiq avtotransport harakatlanmoqda (shundan 736 mingdan ziyodi doimiy ro'yxatda bo'lsa, 175 mingdan ortig'i viloyat hududlaridan kirib keladi) [1].

Shahar aholisining 74 foizi tirbandlikni eng dolzarb muammolaridan biri sifatida qayd etgan. Avtotransport vositalarining chorrahalarda uzoq vaqt to'xtab turishi natijasida yoqilg'i sarfi ortib, atmosferaga zararli gazlar ajralishi keskin kuchaymoqda [2]. Toshkent shahridan tashqari O'zbekistonning boshqa yirik shaharlarida ham gavjum ko'chalarda tirbandlik muammosi mavjud. Mavjud muammolarni bartaraf etish an'anaviy statik (qat'iy taymerli) svetafor tizimlari orqali imkonsiz bo'lib, transport oqimini real vaqt rejimida kompyuterli ko'rish (Computer Vision) va sun'iy intellekt (AI) algoritmlari asosida dinamik boshqaruvchi intellektual transport tizimlarini (ITS) joriy etishni taqozo etmoqda.

YOLO algoritmi obyektlarni aniqlashda keng qo'llaniladi. YOLOv8 modeli yuqori tezlik va aniqlik bilan ajralib turadi. Intellektual transport tizimlarida adaptive svetafor boshqaruvini yo'lga qo'yish maqsadida ko'plab tadqiqotlar amalga oshirilgan. Avtomobillarni aniqlashda neyron tarmoqlarini qo'llash bo'yicha dastlabki muvaffaqiyatli qadamlar Mingxiu Lin va boshqalar tomonidan YOLOv3 va Kalman filtri kombinatsiyasi yordamida amalga oshirilgan bo'lib, ular tirbandlikni boshqarishda 30% lik samaradorlikka erishgan [3]. Biroq, YOLOv3 modelining arxitektura cheklavlari real vaqt rejimidagi yuqori chastotali tasvirlarga tezkor ishlov berish imkonini bermagan. Keyinchalik, Sharma va boshqa mualliflar Edge AI va YOLOv4 modelini integratsiya qilish orqali tizim kechikishini kamaytirishga muvaffaq bo'lishdi [4], ammo model kam yoritilgan (tungi yoki soyali) sharoitlarda obyektlarni aniqlashda past ko'rsatkich namoyish etgan.

IEEE Xplore platformasida chop etilgan tadqiqotda real vaqt rejimida transport vositalarini aniqlash uchun YOLOv9 algoritmi hamda moslashuvchan svetafor signallarini nazorat qilish uchun Chuqur mustahkamlovchi ta'lim (Deep Reinforcement Learning - DRL) modeli muvaffaqiyatli integratsiya qilingan. DRL va YOLOv9 kabi murakkab neyron tarmoqlarining kombinatsiyasi amaliyotda juda yuqori hisoblash resurslarini talab qiladi hamda qaror qabul qilish tezligida ma'lum uzilishlar (latency) keltirib chiqarishi mumkin [5].

Aynan mana shu cheklovni bartaraf etish maqsadida, ushbu tadqiqot ishida hisoblash resurslariga bo'lgan talabni kamaytiruvchi YOLOv8 modeli hamda tezkor qaror qabul qiluvchi diskret chegaraviy intervallar algoritmi kombinatsiyasi taklif etildi.

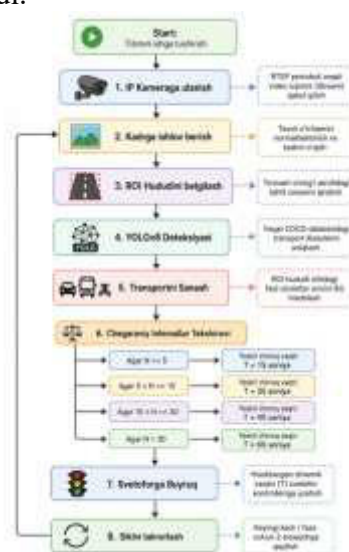
Tizim kamera, YOLOv8 modeli, Python dasturi va Arduino qurilmasidan iborat. Transport vositalari aniqlanadi va ularning soniga qarab svetafor vaqti belgilanadi.

YOLOv8 tarmog‘i aniqlagan obyekt chegaralovchi qutilarining (bounding box) geometric markazini hisoblash [Redmon va boshqalar, 2016] modeliga tayanadi. Aniqlangan koordinatalarning belgilangan ROI maydoniga tegishli ekanligini tekshirish va transport vositalarini diskret sanash mantiqi indicator funksiyalari orqali amalga oshirildi [6].

Chorrahadagi transport oqimi o‘zgaruvchan bo‘lganligi sababli, yashil chiroq davomiyligini hisoblashda uzluksiz chiziqli funksiyalar o‘rniga diskret chegaraviy intervallar modeli ishlab chiqildi. Ushbu model svetafor kontrollerlarining kommunikatsiya tezligini oshiradi. Tizim aniqlangan transport soni (N) ga qarab, yashil chiroq vaqtini (T_{green}) quyidagi qat’iy mantiqiy shart asosida belgilaydi:

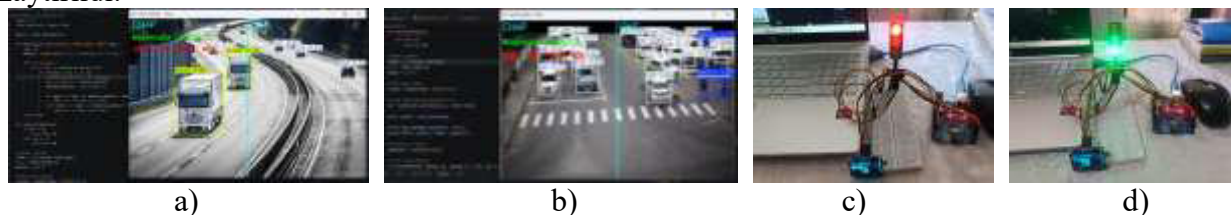
$$T_{green} = \begin{cases} 15 \text{ sek}, & \text{agar } 0 \leq N \leq 5, \\ 30 \text{ sek}, & \text{agar } 5 < N \leq 15, \\ 45 \text{ sek}, & \text{agar } 15 < N \leq 30, \\ 60 \text{ sek}, & \text{agar } N > 30. \end{cases} \quad (6)$$

Svetoorning bir fazasi tugagach, algoritm keyingi sikl uchun IP kameradan yangi ma’lumotni oladi va jarayon uzluksiz takrorlanadi.



1-rasm. YOLOv8 va chegaraviy intervallar asosidagi adaptiv svetofor tizimining ishlash algoritmik sxemasi.

Tizim real vaqt rejimida sinovdan o‘tkazildi. Natijada transport mavjud bo‘lganda yashil vaqt uzaytirildi.



2-rasm. YOLOv8 va chegaraviy intervallar algoritmining video oqimidagi sinov natijalari skrinshotlari: a) transport vositalari soni kam ($N=3$, $T=10$ sek); b) o‘rtacha oqim zichligi ($N=10$, $T=20$ sek); c) va d) Arduino orqali ledlarning boshqarilish holati

Ishlab chiqilgan tizimning amaliy samaradorligini baholash maqsadida shahar chorrahalarining birida olingan kunduzgi video materiallar yordamida eksperiment o‘tkazildi. 2-rasmda ko‘rsatilganidek, IP kameradan olingan kadrda maxsus ajratilgan ROI hududi ichiga kirgan transport vositalari YOLOv8 modeli tomonidan aniqlanib, ustiga cheralovchi qutilar (bounding boxes) chizilgan.

Tungi va noqulay ob-havo tasvirlari bo‘lmagani, faqat kunduzgi ochiq videodan foydalanilgani sababli modelning umumiy aniqlik ko‘rsatkichi (mAP50) **92.2%** ni tashkil etdi, bu esa real vaqt rejimida svetoorni boshqarish uchun to‘liq yetarli hisoblanadi.

Taklif etilgan tizim transport boshqaruvini yaxshilaydi va kelajakda kengaytirish mumkin. Ushbu tadqiqot ishi doirasida zamonaviy intellektual transport tizimlarining eng dolzarb muammolaridan biri – shahar chorrahalarda transport oqimi zichligiga qarab svetofor chiroqlarini dinamik boshqarish modeli ishlab chiqildi va amaliyotda sinab ko‘rildi. An’anaviy qat’iy taymerli svetofor tizimlarining kamchiliklarini bartaraf etish maqsadida taklif etilgan YOLOv8 neyron tarmog‘i va diskret chegaraviy intervallar algoritmi kombinatsiyasi yuqori samaradorlik namoyish etdi. Tadqiqotning keyingi bosqichlarida tizimni yanada takomillashtirish maqsadida tungi va noqulay ob-havo (yomg‘ir, tuman, qor) sharoitlarida ishlay oladigan ma’lumotlar to‘plamini (dataset) shakllantirish, chorrahaning barcha 4 ta yo‘nalishini o‘zaro integratsiya qilish hamda tez yordam, o‘t o‘chirish va boshqa maxsus transport vositalariga ustunlik (prioritet) beruvchi intellektual algoritmlarni qo‘shish rejalashtirilgan.

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UAV-BASED MULTISPECTRAL AND THERMAL IMAGING METHODS AND ALGORITHMS FOR EARLY DETECTION OF WATER AND NITROGEN STRESS AND GRAIN YIELD PREDICTION IN WINTER WHEAT

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Abstract. In Central Asia and other irrigated continental regions, winter wheat (*Triticum aestivum* L.) yields are increasingly constrained by water scarcity and suboptimal nitrogen management. This study proposes an integrated workflow that combines multispectral and thermal infrared imagery acquired from unmanned aerial vehicles (UAVs) with machine-learning algorithms for early detection of water and nitrogen stress and submeter-scale grain yield prediction. Field experiments were conducted over three growing seasons (2021/2022–2023/2024) on irrigated plots under a 4×3 factorial design (irrigation: 100, 75, 50, 25 % of ET_c; nitrogen: 60, 120, 180 kg N/ha). UAV flights were performed at five phenological stages (Z30, Z39, Z55, Z65, Z75) at 40 m altitude, yielding five-band multispectral (B, G, R, RedEdge, NIR) and radiometrically calibrated thermal (8–14 μm) imagery. A unified feature set was built from vegetation indices (NDVI, NDRE, MTCI, REIP, OSAVI, MCARI), the Crop Water Stress Index

(CWSI), Canopy Temperature Depression (CTD), and GLCM texture descriptors. Random Forest, XGBoost, LightGBM, and a one-dimensional convolutional neural network (1D-CNN) were trained under spatial block cross-validation. The combined multispectral–thermal–texture model reached $R^2 = 0.89$ for grain yield prediction at heading (Z55) and 93.6 % overall accuracy for joint water–nitrogen stress classification — 12–15 percentage points higher than spectral-only baselines. SHAP analysis identified NDRE, REIP, CWSI, and RedEdge texture entropy as the most influential features.

Keywords: *winter wheat; UAV; multispectral imaging; thermal infrared; water stress; nitrogen status; CWSI; NDRE; REIP; MTCI; GLCM texture; machine learning; XGBoost; spatial cross-validation; grain yield prediction; precision agriculture; Central Asia.*

1. Introduction

Wheat is a staple cereal cultivated on more than 220 million hectares worldwide and provides a large share of human caloric and protein intake. In Uzbekistan, winter wheat occupies over 1.4 million hectares and represents a strategic component of national food security. In continental and semi-arid irrigated systems, wheat consumes 30–45 % of agricultural water resources. Climate projections indicate that over the next 30 years irrigation water availability in the region may decline by 20–40 %, while heat stress and nitrogen input costs are expected to rise.

Multispectral and thermal sensors mounted on UAV platforms provide high-resolution, on-demand imagery and offer a practical alternative to satellite remote sensing. For wheat, RedEdge-based indices (700–750 nm) such as NDRE, MTCI, and REIP have repeatedly outperformed conventional NDVI in estimating leaf chlorophyll and nitrogen content, because NDVI saturates under dense canopy whereas red-edge reflectance remains sensitive to chlorophyll concentration. Thermal imagery contributes complementary physiological information: under water deficit, stomata close, transpiration decreases, and canopy temperature rises — often several days before visible spectral changes appear. The Crop Water Stress Index (CWSI) captures this process in a normalized form. In parallel, ensemble methods (Random Forest, XGBoost, LightGBM) and deep learning (1D-CNN) consistently outperform classical regression on high-dimensional UAV data. Three gaps nevertheless persist in the literature: (i) most studies address water or nitrogen stress in isolation, although in practice the two occur simultaneously and are physiologically coupled; (ii) GLCM texture features are rarely fused with thermal CWSI; (iii) no complete, reproducible, spatially validated pipeline has been documented for Central Asian winter wheat systems. This thesis directly addresses these gaps. The objectives of the study are: (a) to detect water and nitrogen stress jointly and early under irrigation $\times$ nitrogen regimes; (b) to predict grain yield at submeter resolution across Zadoks growth stages; (c) to compare RF, XGBoost, LightGBM, and 1D-CNN under spatial block cross-validation and to identify the most informative features and phenological windows.

2. Materials and Methods

Experimental site and design.

Trials were carried out over three growing seasons on irrigated wheat fields in Tashkent and Andijan regions of Uzbekistan (40.7–41.3° N; 405–510 m a.s.l.). The climate is continental and semi-arid, with mean annual precipitation of 320–470 mm. Soils are typical and meadow sierozems with sandy-loam texture. Each field was divided into 36 plots (10 $\times$ 15 m) under a 4 $\times$ 3 randomized complete block design: four irrigation levels (100, 75, 50, 25 % of ET_c) and three nitrogen rates (60, 120, 180 kg N/ha). Cultivars 'Andijon-2', 'Yaksart', and 'Krasnodarskaya-99' were sown in early October at 220 kg/ha. Ground-truth data — leaf water potential, stomatal conductance, SPAD, Kjeldahl nitrogen, LAI, grain yield, and grain protein — were collected at five phenological stages (Z30, Z39, Z55, Z65, Z75).

UAV platform and sensors.

A DJI Matrice 300 RTK quadcopter carried two synchronized payloads: (i) a MicaSense RedEdge-MX Dual five-band multispectral camera (475, 560, 668, 717, 840 nm; 12-bit) with a Downwelling Light Sensor (DLS-2); (ii) a FLIR Vue Pro R thermal camera (640 $\times$ 512 px, 8–14 μ m, ± 0.5 °C). Flights were performed between 11:00 and 13:00 local time under clear-sky

conditions at 40 m altitude with 80 % forward and 75 % side overlap. Ground sampling distance was 2.7 cm for the multispectral camera and 5.2 cm for the thermal sensor.

Image processing and feature extraction.

Multispectral imagery was processed in Pix4Dfields and Agisoft Metashape Professional through a standard pipeline: dark-frame and vignetting correction, DLS-based irradiance normalization, empirical line calibration with three Spectralon panels, bundle block adjustment with 12 ground control points, and generation of 4 cm orthomosaics. Thermal imagery was processed in FLIR ResearchIR with emissivity correction ($\epsilon = 0.98$), atmospheric correction, and non-uniformity removal. Wet and dry references for CWSI were obtained from in-field reference plates. From calibrated orthomosaics, seven cereal-oriented vegetation indices were derived: NDVI, NDRE, MTCI, REIP, OSAVI ($L = 0.16$), MCARI, and TVI. CWSI was computed per pixel as $CWSI = (T_{canopy} - T_{wet}) / (T_{dry} - T_{wet})$ after masking soil pixels at $NDVI > 0.45$. GLCM texture features were extracted from the RedEdge and NIR bands (7×7 window, four orientations, 32 grey levels), yielding contrast, homogeneity, entropy, correlation, and angular second moment.

Machine-learning models and validation.

Four models were compared for stress classification and yield regression: Random Forest, XGBoost, LightGBM, and a 1D-CNN. Hyperparameters were tuned with 50-iteration Bayesian optimization. The 1D-CNN had three Conv1D layers (32, 64, 128 filters; kernel 3), batch normalization, dropout (0.3), global average pooling, and two dense layers. To prevent spatial autocorrelation leakage, fields were divided into 60×60 m blocks and five spatial folds were formed; leave-one-season-out (LOSO) tested cross-season generalization. Performance metrics included overall accuracy, weighted F1, and AUC for classification, and R^2 , RMSE, and MAE for regression.

3. Results and Discussion

Early detection of water and nitrogen stress.

The combined multispectral–thermal–texture model classified six stress states (well-watered and well-fertilized; mild and severe water stress; mild and severe nitrogen deficit; combined water-and-nitrogen deficit) with 93.6 % overall accuracy (weighted F1 = 0.93; AUC = 0.97) under spatial block CV. Spectral-only models reached 78–82 %, thermal-only models 81–84 %. The RedEdge band contributed most to separating mild nitrogen deficit from mild water stress — two states that appear almost identical in NDVI but separate cleanly in NDRE and CWSI. GLCM texture added 2.5–3.5 percentage points, especially when distinguishing lodged or unevenly tillered canopies from uniformly stressed ones.

Grain yield prediction.

The best performance was achieved at heading (Z55) by XGBoost trained on the full feature set: $R^2 = 0.89$; RMSE = 412 kg/ha; MAE = 318 kg/ha. LightGBM ($R^2 = 0.87$) and 1D-CNN ($R^2 = 0.86$) followed closely, although the 1D-CNN matched ensembles only with the full feature set. Prediction accuracy increased monotonically through the season: R^2 was 0.64 at Z30, 0.79 at Z39, 0.89 at Z55, and 0.91 at Z75. Operationally, Z55 was selected as the optimal forecasting window because it combines high accuracy with sufficient lead time (~30 days) for top-dressing, fungicide, and harvest decisions.

Feature importance and phenological windows.

SHAP analysis identified four dominant features for the XGBoost model: NDRE, REIP, CWSI, and RedEdge GLCM entropy. Their relative importance shifted with phenology: CWSI and CTD dominated at Z30–Z39 (early water stress suppresses tillering); NDRE, MTCI, and REIP led at Z55–Z65 (nitrogen status governs grain set and yield potential); texture entropy gained importance at Z75, when lodging and senescence-induced canopy heterogeneity became the most diagnostic signal. This pattern is fully consistent with wheat physiology.

Discussion.

Results confirm that single-sensor UAV approaches are insufficient for joint water–nitrogen assessment in winter wheat. NDVI saturates in dense canopies ($LAI > 4$) and reacts several days after stress onset. RedEdge indices respond directly to chlorophyll and shift within hours after

nitrogen application, creating the temporal margin required for variable-rate irrigation and fertilization. Fusing spectral and thermal data is decisive for disentangling water from nitrogen stress: NDRE/REIP drop mainly under nitrogen deficit, whereas CWSI rises mainly under water deficit, yielding a four-quadrant decision matrix (water only / nitrogen only / both / neither). Methodologically, spatial block CV is conservative but realistic — random k-fold inflated R^2 by 0.08–0.12 in preliminary checks, confirming spatial leakage. Limitations: only two regions; no submeter soil-moisture sensors; CWSI depends on references; diseases (yellow rust, septoria) were not included. Future work should add Sentinel-2 fusion, cross-cultivar and cross-soil generalization, and coupling with physiological models (APSIM-Wheat, DSSAT-CERES).

4. Conclusion

This study presents a reproducible methodological pipeline that combines UAV multispectral, thermal, and texture data with machine learning for early joint detection of water and nitrogen stress and grain yield prediction in irrigated Central Asian winter wheat. The proposed approach reached 93.6 % accuracy in six-class stress classification and $R^2 = 0.89$ in yield prediction at Z55, exceeding spectral-only baselines by 12–15 percentage points. Four practical conclusions emerge: (1) the RedEdge band (NDRE, MTCI, REIP) is not optional but essential for winter wheat, because NDVI saturates in dense canopies; (2) thermal data complements spectral data in resolving the water-versus-nitrogen ambiguity; (3) gradient-boosting ensembles (XGBoost, LightGBM) match deep architectures on mid-sized UAV datasets while remaining interpretable via SHAP; (4) spatial block validation should become the default in precision-agriculture studies, otherwise model performance is systematically overestimated. The proposed approach can be operationalized as a decision-support tool for variable-rate irrigation, variable-rate nitrogen application, within-field stress mapping, and seasonal yield forecasting. It can also be adapted to other irrigated cereals (barley, rye, triticale) and to rainfed wheat systems, supporting climate-resilient and resource-efficient agriculture.

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REAL-TIME DRIVER DROWSINESS DETECTION USING FACIAL LANDMARKS, EAR, MAR, AND HEAD POSE ESTIMATION

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Annotation. Driver fatigue is one of the leading causes of road traffic accidents. This work presents a lightweight, real-time driver drowsiness detection system that fuses three complementary facial cues — the Eye Aspect Ratio (EAR), the Mouth Aspect Ratio (MAR), and the head-pose pitch angle — extracted from 468 facial landmarks of the MediaPipe Face Mesh model. A temporal voting mechanism over twenty consecutive frames suppresses false alarms produced by ordinary blinks or speech. The system runs at 28–30 fps on commodity CPU hardware and achieves 92.4% accuracy and 0.93 F1-score in mixed real-world conditions.

Keywords: driver drowsiness; eye aspect ratio; mouth aspect ratio; head pose estimation; MediaPipe; computer vision; road safety.

Introduction

According to the World Health Organization, approximately 1.19 million people die in road traffic accidents every year, and a significant proportion of these crashes are caused by driver fatigue and microsleep episodes [1]. Unlike alcohol impairment, drowsiness is difficult to self-assess, which makes automatic, non-intrusive monitoring particularly valuable.

Computer-vision-based drowsiness detection has become the most practical option for mass deployment because it requires only a low-cost camera and no sensors attached to the driver. Early approaches used the Eye Aspect Ratio (EAR) introduced by Soukupová and Čech [2]; however, EAR alone cannot distinguish microsleep from voluntary long blinks. Recent works combine multiple facial cues and have reported practical accuracies in the 90–93% range [3], [4].

This paper proposes a multi-cue, CPU-only pipeline that fuses EAR, the Mouth Aspect Ratio (MAR), and the head-pose pitch angle through a short temporal voting window, providing high reliability without GPU acceleration or training data.

Methodology

The proposed system consists of four sequential modules: (1) video acquisition from a standard webcam, (2) extraction of 468 facial landmarks via the MediaPipe Face Mesh model [5], (3) computation of three drowsiness indicators, and (4) a multi-signal decision module.

The Eye Aspect Ratio measures the ratio between the vertical and horizontal eye distances:

$$EAR = (||p_2 - p_6|| + ||p_3 - p_5||) / (2 \cdot ||p_1 - p_4||) \quad (1)$$

where $p_1 \dots p_6$ are six eye landmarks. The Mouth Aspect Ratio is defined analogously over eight mouth landmarks $m_1 \dots m_8$:

$$MAR = (||m_2 - m_8|| + ||m_3 - m_7|| + ||m_4 - m_6||) / (3 \cdot ||m_1 - m_5||) \quad (2)$$

The head-pose pitch angle is estimated by solving the Perspective-n-Point problem between six anatomically stable points and a generic 3D head model using OpenCV's solvePnP routine.

Three counters c_e , c_m , c_p are incremented when the corresponding indicator violates its threshold and reset to zero otherwise. A drowsiness alert is issued when:

$$\max(c_e, c_m, c_p) \geq N, \text{ with } N = 20 \text{ frames} \quad (3)$$

At 30 fps, $N = 20$ corresponds to about 0.67 s — long enough to filter out ordinary blinks (100–400 ms) but short enough to react before a microsleep causes loss of control. The empirical thresholds are $\text{EAR} < 0.21$, $\text{MAR} > 0.55$, and $|\Delta\text{pitch}| > 15^\circ$.

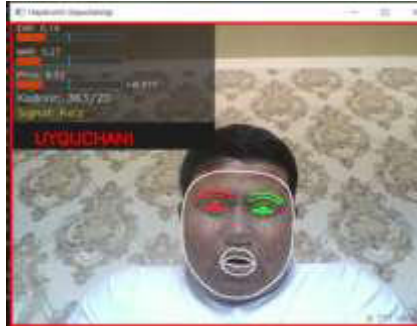


Fig. 1. Triggered drowsiness alert: $\text{EAR} = 0.14$, dominant signal source — eye (Ko ‘z’); system displays UYQUCHAN! ("Drowsy!").

Experimental Results

The system was implemented in Python 3.10 with OpenCV 4.9 and MediaPipe 0.10 and tested on a laptop with Intel Core i5-10210U CPU (no GPU). Five recorded scenarios were used: alert driving, long eye closure, yawning, head nodding, and a mixed session. Ground-truth labels were obtained by manual annotation. Table 1 summarises the results.

Table 1. Per-scenario classification performance.

Scenario	Frames	Correct	Accuracy	F1-Score
Alert driving	300	297	0.99	—
Long eye closure	100	94	0.94	0.95
Yawning	50	47	0.94	0.93
Head nodding	48	42	0.88	0.89
Mixed real conditions	486	474	0.92	0.93

The system achieves an overall accuracy of 92.4% and an F1-score of 0.93 in mixed real-world conditions, while sustaining 28–30 frames per second on a standard CPU. False positives occur mainly during exaggerated facial expressions and prolonged speech, where the MAR temporarily exceeds the yawn threshold. The temporal voting mechanism ($N = 20$ frames) successfully suppresses false positives caused by ordinary blinks: no isolated blink lasting 7–12 frames triggered an alert during the experiments. The lowest individual accuracy (88%) was observed for head-nodding events, which is partly explained by the inherent ambiguity between deliberate looking-down and fatigue-induced nodding.

Compared with deep-learning baselines that report ~95–96% accuracy [3] but require GPU acceleration and large annotated training sets, the proposed pipeline offers a favourable trade-off between accuracy, interpretability, hardware cost, and absence of any training requirement. Each alert can be traced back to a specific signal source (eye, mouth, or head), which makes the system fully interpretable. These properties make it especially suitable for low-cost in-vehicle deployment in emerging markets.

Among the three indicators, EAR was found to be the strongest single predictor of microsleep, MAR was the earliest predictor of fatigue (yawns typically appear several minutes before the first microsleep), and pitch was the most informative cue during highway driving, where the head tends to nod forward. The combination of the three covers a substantially wider range of fatigue patterns than any single feature alone.

Conclusion

A real-time driver drowsiness detection system that fuses three complementary facial cues — the Eye Aspect Ratio, the Mouth Aspect Ratio, and the head-pose pitch angle — was presented. A

short temporal voting window of twenty consecutive frames reliably suppresses false positives caused by ordinary blinks or speech, while still reacting within less than one second to genuine drowsiness events. The system runs at 28–30 fps on a standard CPU laptop without any GPU, requires no training data, and achieves 92.4% accuracy and 0.93 F1-score in mixed real-world conditions.

Future work will focus on five directions: (i) integration of an infrared camera channel to maintain reliability under night-time and low-light conditions; (ii) addition of gaze-direction analysis based on MediaPipe's refined iris landmarks; (iii) personalised baseline calibration during the first 30 seconds of driving to account for individual differences in eye and mouth geometry; (iv) integration with an on-board audio module that issues progressively louder alerts; and (v) deployment on embedded boards such as Raspberry Pi 5 and NVIDIA Jetson Nano for real in-vehicle testing under naturalistic driving conditions.

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SOIL FERTILITY PREDICTION USING RANDOM FOREST ALGORITHM: IMPROVING ACCURACY USING INTUITIONISTIC FUZZY LOGIC

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Abstract. This study analyzed various mathematical and machine learning methods for predicting soil fertility. The primary objective of the study was to determine a fertility index based on soil parameters and compare the performance of different models. Three models were considered: the Linear Weighted Model (LWM), the Intuitionistic Fuzzy Sets (IFS) model, and the Random Forest algorithm. Soil moisture, nitrogen content, temperature, precipitation, and pH were selected as the main input parameters.

Introduction. In recent years, advances in artificial intelligence technologies have led to increased attention to forecasting in agriculture. Advances in machine learning (ML) have significantly increased the efficiency of agricultural operations. With the global population growing and the impact of climate change on agricultural production, accurate crop yield forecasting has become crucial for ensuring food security and optimizing resource allocation [1]. The Random Forest algorithm generates multiple decision trees based on randomly selected samples from the original dataset. Each tree is trained on a subset of the data selected using bootstrapping. This process is called bootstrap aggregating (bagging). During the construction of each tree, features are

also randomly selected [2]. As a result, the trees are independent of each other, reducing the overall model error. During the prediction process, the Random Forest algorithm considers the results of each tree. If the problem is classification, the final result is determined based on the majority of tree votes. If the problem is regression, the average of the outputs of all trees is calculated. This process is mathematically expressed as follows [3]:
here

$$\hat{y} = \frac{1}{K} \sum_{k=1}^K T_k(x)$$

$T_k(x)$ - is the prediction obtained by the k-th tree,

K - number of trees,

$\hat{y}$ - the final forecast generated by the model.

The Random Forest algorithm has several advantages. First, it provides robust results when working with large data sets. Second, the model is less susceptible to overfitting. Third, the algorithm allows for feature significance assessment. This, in turn, helps determine which factors have the greatest impact on the results [4]. In agriculture, the Random Forest algorithm is widely used to assess soil fertility, predict crop yields, recommend crop varieties, and analyze agroecological parameters [7]. For example, crop yields can be predicted based on parameters such as nitrogen, phosphorus, and potassium content in the soil, temperature, moisture, pH, and precipitation [5-6]. Because the Random Forest algorithm is capable of identifying complex and nonlinear relationships between these parameters, it is effectively used in agricultural decision support systems [1].

Empirical Model

The complete model can be written as follows:

$$\hat{y} = RF(M, N, T, R, pH)$$

Here

$$F = 0.25Q_M + 0.25Q_N + 0.15Q_T + 0.20Q_R + 0.15Q_{pH}$$

and $RF(\bullet) - F$ A Random Forest classifier trained on a sample generated based on the index.

The dataset developed for training the model initially consisted of 5 values. During training, it was determined that the data size was insufficient. To address this issue, the initial 5 observations were expanded to 30, which improved the model's accuracy. The code snippet below illustrates this process.

After increasing the initial data volume and training the model, the forecasting stage is performed. The presented code forecasts the fertility index using the trained Random Forest model and calculates the statistical characteristics of the tree ensemble. This process can be represented as a sequence of mathematical formulas.



Figure 2. Fertility Index Forecast Results under Optimal Conditions

Conclusion

This study examined the problem of predicting soil fertility based on its parameters and compared three different approaches: a Linear Weighted Model, an Intuitionistic Fuzzy Sets model,

and a Random Forest algorithm. Key factors included agroecological parameters such as soil moisture, nitrogen content, temperature, precipitation, and pH, and their impact on soil fertility was modeled.

The results showed that although the linear weighted model has a simple computational approach, it is unable to fully capture complex and nonlinear relationships. The Intuitionistic Fuzzy model accounts for uncertainty and, in some cases, performs effectively with incomplete data. However, the Random Forest algorithm, based on an ensemble of decision trees, demonstrated high accuracy in identifying complex relationships between parameters. The statistical evaluation results also confirmed that this model has the highest R^2 value.

agroecological factors, using satellite data, and remote sensing technologies.

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NEYRON KOPULA MODELINI IKKI AGENTLI UMR DAVOMIYLIGI JARAYONLARIGA TATBIQLARI

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Umr davomiyligi tahlilida tadqiqotchilar ko'pincha egizaklar, turmush o'rtoqlar, yoki texnik tizimning ikki komponenti kabi bog'liq ikki agentning umr davomiyligini o'rganadilar [1]. Umr davomiyligi orasidagi bog'liqlik umumiy genetik omillar, tashqi muhit ta'siri, yoki umumiy stres faktorlaridan kelib chiqishi mumkin. Klassik umr davomiyligi (survival) analizi ko'pincha umr davomiyligi bog'liqsiz deb faraz qiladi yoki zaiflik (frailty) modellari hamda proporsional havf (proportional hazard) yondashuvlari orqali parametrik bog'liqlik strukturasini qo'llaydi. Biroq real tizimlarda bog'liqlik nochoziqli, vaqt bo'yicha o'zgaruvchi, murakkab strukturalangan bo'lishi mumkin.

Kopula nazariyasi marginal umr davomiyligi funksiyalarni bog'liqlik strukturasidan ajratish imkonini beruvchi moslashuvchan matematik apparat hisoblanadi. Sklar teoremasiga ko'ra, har qanday qo'shma survival funksiya marginal survival funksiyalar va kopula orqali ifodalanishi mumkin [3]

$$S(t_1, t_2) = C(S_1(t_1), S_2(t_2)),$$

bu yerda $S(t_1, t_2) = P(T_1 > t_1, T_2 > t_2)$ birgalikdagi umr davomiyligi (survival) funksiyasi; $S_i(t) = P(T_i > t)$ bu i -agent uchun marginal umr davomiyligi funksiyasi; $C: [0,1]^2 \rightarrow [0,1]$ ikki o'lchovli kopula funksiyasidir.

So'nggi yillarda chuqur o'rganish (deep learning) murakkab nochiziqli bog'lanishlarni o'rganishda yuqori samaradorlikni namoyish etdi. Neyron tarmoqlar qat'iy parametrik cheklovlarisiz yuqori o'lchamli bog'lanishlarni moslashuvchan tarzda o'rganish imkonini beradi. Har bir $i \in \{1,2\}$ agent uchun kumulyativ havf funksiyasi quyidagicha modellashtiriladi

$$H_i(t | X) = NN_i(t, X; \psi_i),$$

bu yerda t — vaqt, $X \in \mathbb{R}^d$ — kovariatalar vektori, NN_i — parametrlar ψ_i ga ega feedforward neyron tarmoq [2]. Chiqish qiymati manfiy bo'lmisligi cheklanadi. Shunda marginal umr davomiyligi funksiya

$$S_i(t | X) = \exp(-H_i(t | X)),$$

ko'rinishda bo'ladi.

Taklif etilgan neyron kopula modeli klassik umr davomiyligi analizni bir necha muhim yo'nalishlarda kengaytiradi [4]. Birinchidan, proporsional havf modellardan farqli ravishda, model qat'iy chiziqli bog'lanishlarni talab qilmaydi. Neyron tarmoqlar murakkab havf strukturalarini ma'lumotlardan o'rganadi. Ikkinchidan, bog'liqlik parametri kovariatalarga bog'liq holda o'zgaradi. Bu agentlar orasidagi bog'liqlik darajasini dinamik tarzda modellashtirish imkonini beradi. Uchinchidan, identifikatsiyalanuvchanlik va asoslilik teoremlari modelning matematik jihatdan qat'iy asoslanganligini ko'rsatadi.

Mazkur ilmiy ishning asosiy maqsadi o'ng tomondan senzuralangan ma'lumotlar uchun ikki agentli neyron kopula umr davomiyligi modelini ishlab chiqish; neyron havf funksiyalarini qurish; kopula parametrlarini kovariatalarga bog'liq holda modellashtirish; modelning identifikatsiyalanuvchanligini isbotlash va maksimum ehtimollik bahosining asoslilikini asoslashdan iborat. Olingan natijalar neyron kopula umr davomiyligi modellari murakkab bog'liq umr davomiyligi tizimlarini modellashtirish uchun samarali va matematik jihatdan qat'iy vosita ekanligini ko'rsatadi.

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6-SHO'BA. MASHINALI O'RGATISH VA INTELLEKTUAL ALGORITMLAR

SUN'IY INTELLEKTNING SALBIY TOMONLARI

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Annotatsiya. Ushbu maqolada bugungi kunda dunyodagi barcha davlatlarda va har bir sohada sun'iy intellektlar asosida yaratilgan avtomatik qurilmalar keng tadbiq etilayotganligi natijasida katta iqtisodiy natijalarga erishilayotganligi barchaga ma'lum bo'lsa ham uning salbiy tomonlari ham ko'payib borayotganligi natijasida korxonalar, tashkilotlar va ayniqsa jismoniy shaxslar juda katta moliyaviy, iqtisodiy va ma'naviy zarar keltirilayotganligi tahlil qilingan va ularga qarshi himoyalash usullari keltirilgan.

Intellektual tizimlarni rivojlanishi asosan 1988-yilda Pospelov Dimitriy Aleksandrovich boshchiligidagi yangi yo'nalish – sitatsion boshqarish termini va tizimi yaratilganligi hamda sun'iy intellekt assotsiatsiyasi tashkil etilganligidan so'ng juda tezlashib ketganligini barcha ushbu yo'nalish bo'yicha ishlayotgan mutaxassislar yaxshi bilishadi.

Bugungi kunga kelib sun'iy intellekt (SI) ning turlari juda ham ko'payib bormoqda - avtotransport vositalari, tibbiyotda ishlatiladigan kobotlar, tabiiy ofatlarda yordam beruvchi, ko'ngil ochar, gumanoid, sanoat va kosmik robotlari keng tarqalib bormoqda. Bundan tashqari har xil turdagi robotlar, kobotlar va botlar faoliyat olib borilmoqda.

Har qanday yangi yaratilayotgan axborot texnologiyalarining foydali va musbat tomonlariga qaramasdanularning kamchiliklari va salbiy tomonlari ham kelib chiqmoqda. Lekin ko'p joylarda bunday kamchiliklarga e'tibor berilmay kelmoqda.

Hozirgi kunda har xil brauzerlar va telegramm orqali uzatilayotgan hamda yangi versiyalari ishlab chiqilayotgan neyrotarmoqlar asosida yaratilgan ChatGPT va bosh Sillar har bir insonning bergan savollariga qisqa vaqtlar ichida javob olinayotgani ham barchaga ma'lum. Bularning salbiy tomonlarini bir tahlil qilib chiqishga harakat qilamiz.

1. Bizning yurtimizda ta'lim olayotgan o'quvchilar, oliy ta'lim muassasalarida o'qiyotgan talabalar, magistrlar, ilmiy tadqiqot olib borayotgan tadqiqotchilar maqolalar yozish uchun, bitiruv malakaviy ishlarini, dissertatsiya ishlarini ushbu botlar orqali amalga oshirmoqdalar.

2. Axborot-kommunikatsiya texnologiyalari yo'nalishi bo'yicha ta'lim olayotgan talabalarga har xil algoritmik tillarida ma'ruza va amaliy mashg'ulotlar qiziqarli bo'lmay qolmoqda. Bundan tashqari ushbu yo'nalish bo'yicha ishlayotgan professor-o'qituvchilari tomonidan chop etilgan o'quv qo'llanma va darsliklarini o'qimay qo'yishmoqda. Ularda mustaqil fikrlash va qiziqish kamayib bormoqda, chunki ushbu ChatGPT ga kirib xohlagan algoritmik tilda yozib bergin deb topshiriq berilganda bir necha soniyalar ichida ushbu tilda dastur kodini misollar bilan chiqarib bermoqda.

3. Barchaga ma'lumki, kompyuter tarmoqlari va simli, simsiz mobil telekommunikatsiya aloqa kanallari orqali uyushtirilayotgan har xil turda tahdidlar, hujumlar ham intellektual tizimlarning bilimlar bazalaridan foydalanib amalga oshirilmoqda. Bularga misol sifatida asosiy hujumlarga Fishing, Vizing, Farminglardan tashqari zamonaviy Deepfake, Deepvoice va har xil turdagi zararli dasturiy vositalar hisoblanadi.

Deepfake - bu insonning haqiqiy qiyofasini, ovozi yoki xatti-harakatlarini taqlid qiluvchi neyron tarmoqlar yordamida yaratilgan audio, video yoki grafik material hisoblanadi. Bunday texnologiyalar yuzlarni almashtirish, ovozni sintez qilish va video yozuvlarni asl nusxadan ajratish juda qiyin bo'lishi uchun o'zgartirish imkonini beradi. SI faqat o'rganish uchun materiallarni, ya'ni odamning ovozi yoki tashqi ko'rinishining namunasini talab qiladi.

Deepvoice - bu SI jabrlanuvchini aldash uchun haqiqiy shaxs - qarindoshi, rahbari yoki hamkasbi - nutqini taqlid qiluvchi soxta ovozli qo'ng'iroqlar yoki audio xabarlarini yaratadigan deepfake turi hisoblanadi. Ushbu texnologiya ovozning bir necha soniya yozib olishda ishonchli nusxasini yaratishi mumkin. Bu uni ommaviy firibgarlik sxemalari uchun ochiq qiladi: yozuvning qisqa qismidan model taxminan 85% gacha bo'lgan ovozni moslashtirishga qodir [1,3].

Bulardan tashqari IT sohasida ishga joylashish bilan bog'liq firibgarlik boshlandi. Ariza beruvchilar tomonidan IT-ish bilan bog'liq firibgarlik - bu hujum bo'lib, unda tajovuzkor soxta hujjatlar, xayoliy profillar va ba'zan intervyu olish uchun deepfakelardan foydalangan holda o'zini bo'sh ish o'rinlariga nomzod sifatida ko'rsatadi. Uning maqsadi yangi xodim niqobi ostida korporativ tizimlarga kirish, kompaniyaga kirish va nozik ma'lumotlar yoki hisob ma'lumotlarini o'g'irlashdir. Ko'pincha bunday "ariza beruvchilari" bir vaqtning o'zida bir nechta kompaniyalarda intervyu o'tkazadilar, kirib borishga urinishlarni kengaytiradilar va muvaffaqiyatli murosaga kelish imkoniyatlarini oshiradilar.

Soxta ishga joylashish sxemasi: tajovuzkor nozik ma'lumotlarga kirish uchun bir nechta kompaniyalarga ishga kirishga harakat qilmoqda. Bu ichki tizimlarning buzilishi, ma'lumotlarning sizib chiqishi va biznes uchun jiddiy obro' va moliyaviy yo'qotishlarga olib keladi.

"Yovuz egizak" (Evil Twin). login va parollarni, bank kartalari ma'lumotlarini, yozishmalar va brauzer tarixini o'g'irlash.

SI-vishing (ovozli fishing). Deepfakening ovozli turi. SI bir necha soniya yozib olishda ovozni nusxalaydi. Jabrlanuvchi bilan muloqot qilish imkonini beradi.

Romantik skame. SI bir vaqtning o'zida minglab odamlar bilan suhbatlashadi. Ishonch illyuziyasini yaratadi, muloqotni shaxsiylashtirish uchun ijtimoiy tarmoq ma'lumotlaridan foydalanadi.

Dropperlar. Slayderlar - firibgarlarning moliyaviy sxemalarida vositachilardir. O'g'irlangan pulni qabul qiladigan odamlar. Kuratorlar uchun pul o'tkazing yoki yechib oling. Ular onlayn-bankingga kirish huquqiga ega kartani uzatadilar. O'q kim slayderlar - firibgarlarning moliyaviy sxemalarida vositachilari.

Kriptoalyuta va firibgarlik. Giyohvand moddalar, qimor o'yinlari, intellektual mulkni o'g'irlash. Pul yuvish, moliyaviy piramidalar. Kriptoalyutalar - bu tez daromad va'dasi bilan mablag'lar va investitsiyalarni jalb qilish usuli.

Firibgarlarning sxemasi. Ular bankka «mijozdan qo'ng'iroq qilishadi». Ular shaxsiy ma'lumotlarni chaqiradilar va SI bilan ular ovozni taqlid qiladilar. Xaritani bloklash sabablari: yo'qotish, o'g'irlik va boshqalar. Jabrlanuvchiga tahdid qilib pul talab qilishadi. Shunday qilib, SIning zararli tomonlarini quyidagicha tasniflash bo'ladi:

1.Moliyaviy tahdidlar:

- SI yordamida kiberfiribgarlikning kuchayishi;
- pul va ma'lumotlarni o'g'irlanishi;
- jinoiy sxemalarni avtomatlashtirishi va boshqalar.

2.Maxsus xavf zonasi:

- voyaga etmaganlarning qurbonlari sonining ko'payishi;
- qo'ng'iroqlar va xabarlar (maktablar, davlat idoralari, aloqa operatorlari) orqali hujumlarni ko'payishi.

3.Pullarni o'g'irlash:

- kiberfiribgarlik;
- soxta bank hisoblari ko'p pul o'tkazmalari,
- mablag'larni aralashtirish;
- moliyaviy oqimlarning chalkashligi;
- kripto platformalar;
- jinoiy faoliyatni qonuniylashtirish / moliyalash va boshqalar.

Ushbu hujumlardan uzatilayotgan, qabul qilinayotgan va saqlanayotgan ma'lumotlarni himoyalash uchun ushbu intellektual tizimlar yordamida biz tomondan bir necha usullar ishlab chiqilgan [2,4,5].

Shuning uchun ushbu maqolada kompyuter tarmoqlari orqali kelayotgan har xil turdagi hujumlarni aniqlash va ularni bartaraf etish maqsadida SI texnologiyalaridan foydalanishga asoslangan usul taqdim etilgan. Tadqiqotda hozirgi kunda ishlanayotgan an'anaviy xavfsizlik usullarini yengib o'tishga qodir bo'lgan murakkab kiber tahdidlar muammosi ko'rib chiqilgan.

Mashinaviy o'rganish algoritmlari va real vaqtli tarmoq trafagini tahlil qilishni birlashtiruvchi intellektual tizim ishlab chiqilgan. Bu tizim orqali potentsial hujum turlarini, xatti-harakatlarini aniqlash natijasida ularni bartaraf etish yo'llari va tajriba asosida olingan ilmiy tadqiqot natijalari keltirilgan. Olingan tajribalar natijalarning tahlili bugungi kunda barchaga ma'lum bo'lgan himoya vositalariga nisbatan aniqlik darajasining va javob olish tezligining yuqori ekanligini ko'rsatdi. Taklif etilayotgan usul va ishlab chiqilgan algoritm har xil turdagi tashkilotlar va korxonalarda kompyuter tarmoqlari orqali kelayotgan tahdidlarni aniqlash, ma'naviy yoki iqtisodiy zarar keltirishi mumkin bo'lgan hollarda operativ real vaqtda bartaraf etish uchun qo'llash taklif etilgan [3,4].

Mazkur tadqiqot SI texnologiyalarining kompyuter tarmog'i xavfsizligini avtomatlashtirilgan aniqlash va bartaraf etish orqali kuchaytirishdagi samaradorligini ko'rsatdi. Taklif qilingan tizim nazoratli va nazoratsiz mashinali o'qitish usullarini birlashtirib, mavjud bo'lgan va yangi turdagi tahdidlarni aniqlashga qodir ekanligini tasdiqlaydi. Ya'ni avtomatik ravishda hujumlarga javob berish vaqti keskin kamaydi, bu esa hujumlarning zarar yetkazishini oldini olish imkonini beradi. Taklif etilayotgan intellektual tizim yangi hujumlardan o'rganib va o'zini mustaqil tarzda takomillashtirib boradi.

Ushbu taklif etilgan va ishlab chiqilgan algoritm asosida tarmoqlar orqali kirib kelayotgan har xil turdagi hujumlarni aniqlash va ularni bartaraf etish jarayonida juda katta yordam berishini ta'kidlashimiz mumkin.

Umumiy xulosa sifatida barcha chop etilayotgan maqolalarni, bitiruv malakaviy ishlarini va yoqlanayotgan dissertatsiya ishlarini chuqur antiplagiat dasturlari orqali tekshirilib borishligi, xakerlar tomonidan uyishtirilayotgan tahdidlarga va hujumlarni qarshi tashkiliy, texnikaviy va dasturiy vositalarni rivojlantirish taklif etiladi.

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BLOCKCHEYN TEXNOLOGIYASI ASOSIDA MOLIVAVIY TRANZAKSIYALARNI NAZORAT QILISH TIZIMI

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Annotatsiya. Ushbu maqolada zamonaviy moliyaviy tranzaksiyalarni nazorat qilishning innovatsion usullari tahlil qilinadi. Blockcheyn texnologiyasining smart-kontraktlar, markazlashmagan ma'lumotlar bazasi va audit izlari kabi asosiy komponentlari asosida moliyaviy

operatsiyalarni shaffof va xavfsiz boshqarish imkoniyatlari o'rganilgan. Maqolada blockcheyn asosidagi nazorat tizimining an'anaviy moliyaviy tizimlardan ustun jihatlari ilmiy asoslab berilgan.

Kalit so'zlar: blockcheyn, smart-kontrakt, DLT, audit izlari, moliyaviy tranzaksiya, kriptografiya, konsensus mexanizmi.

KIRISH

Zamonaviy raqamli iqtisodiyotda moliyaviy tranzaksiyalarning hajmi va murakkabligi ortib borayotganligi sababli, ularni samarali nazorat qilish muammosi dolzarb ahamiyat kasb etmoqda. An'anaviy markazlashgan moliyaviy tizimlar ko'pincha shaffoflik yetishmasligi, yuqori operatsion xarajatlar va potensial firibgarlik xavfi bilan bog'liq muammolarga duch keladi. Blockcheyn texnologiyasi ushbu muammolarni hal qilishda yangi imkoniyatlarni taklif etadi.

Blockcheyn - bu bitimlar yozib boriladigan va ko'p nusxada saqlanadigan markazlashmagan raqamli reyestrdir. Uning moliyaviy tranzaksiyalarni nazorat qilishdagi asosiy afzalliklari:

- Dezentralizatsiya - ma'lumotlar bir nechta tugunlarda saqlanadi
- Shaffoflik - barcha tranzaksiyalar ochiq ko'rinadi
- O'zgartirib bo'lmazlik - kiritilgan ma'lumotlarni o'zgartirib bo'lmaydi
- Kriptografik himoya - ma'lumotlar kuchli shifrlash algoritmlari bilan himoyalangan

Blockcheyn — bu ketma-ket bog'langan, o'zgartirib bo'lmaydigan bloklardan iborat tarqalgan raqamli reyestrdir. Har bir blok raqamli imzo bilan himoyalangan va tarmoqning barcha ishtirokchilarida mavjud bo'lib, ma'lumotlar markazlashmagan holda saqlanadi.

Blockcheynning asosiy komponentlari

- Bloklar va xesh-funksiyalar
- Tarmoq ishtirokchilari (node)
- Konsensus algoritmlari (PoW, PoS, PBFT va boshqalar)
- Kriptografik mexanizmlar
- Tarqalgan reyestr (Distributed Ledger)

Markazlashmagan boshqaruvning afzalliklari

- Bitta markaz funksiyasi yo'qligi sababli tizim buzilishga kam moyil.
- Ma'lumotlarning o'zgartirilishi deyarli imkonsiz.
- Tarmoqdagi barcha ishtirokchilar uchun yagona haqiqat manbai mavjud.

Smart-kontraktlar orqali tranzaksiyalarni avtomatlashtirish

Smart-kontraktlar - bu oldindan belgilangan shartlar bajarilganda avtomatik ravishda amalga oshiriladigan dasturiy kodlar. Moliyaviy nazorat sohasida ular quyidagi vazifalarni bajaradi:

Smart-kontraktlar — bu aniq belgilangan shartlarni avtomatik bajaradigan, blockcheyn asosida ishlovchi dasturiy modullar. Ular moliyaviy operatsiyalarni inson omilisiz bajarish imkoniyatini beradi.



1-rasm. Smart kontraktlarning ishlash mexanizmi



2-rasm. Smart-kontrakt tarkibi

Markazlashmagan ma'lumotlar bazasi — blockcheynning asosiy ustunliklaridan biri bo'lib, ma'lumotlarni bitta markazda yig'masdan, tarmoq bo'ylab tarqatadi.

XULOSA VA TAKLIFLAR

Blockcheyn texnologiyasi moliyaviy tranzaksiyalarni nazorat qilish tizimini tubdan takomillashtirish imkoniyatlarini beradi. Ushbu texnologiyani joriy etish quyidagi qadamlar orqali amalga oshirilishi mumkin:

1. Bosqichma-bosqich o'tish strategiyasini ishlab chiqish
2. Qonunchilik bazasini yangi texnologiyalar talablariga moslashtirish
3. Mutaxassislarni tayyorlash va malakasini oshirish
4. Xavfsizlik protokollarini doimiy yangilab borish

Blockcheyn asosidagi moliyaviy nazorat tizimini joriy etish nafaqat tranzaksiyalarning shaffofligini oshiradi, balki butun moliya tizimining ishonchligini oshiradi.

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SOFT-SKILLS KO'RSATGICHLARI ASOSIDA TA'LIM YO'NALISHLARINI ANIQLASHNING MASHINAVIY O'QITISH VA INTELLEKTUAL ALGORITMLAR

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Annotatsiya. Tegishli ta'lim yo'nalishini tanlash maktab bitiruvchilari uchun juda muhim muammo hisoblanadi, chunki noto'g'ri akademik tanlovlar ko'pincha pastmotivatsiyaga, o'quv natijalarining pasayishiga va ishchi kuchini samarasiz tayyorlashga olib keladi. An'anaviy yo'naltirish usullari odatda cheklangan qisqa muddatli ko'rsatkichlar va subyektiv baholashlarga asoslangan bo'lib, bu ularning bashoratli aniqligini cheklaydi. Maqolada maktab bitiruvchilarining ta'lim yo'llarini o'n yillik davr davomida to'plangan uzoq muddatli akademik ko'rsatkichlar va Soft-Skills ko'nikmalarini tahlil qilish orqali aniqlash uchun mashinani o'rganishga asoslangan model taklif qilingan.

KIRISH.

Raqamli texnologiyalarning jadal rivojlanishi zamonaviy ta'lim tizimlarini sezilarli darajada o'zgartirdi, bu esa akademik rejalashtirish va kasbga yo'naltirishda ma'lumotlarga asoslangan yondashuvlarga talabni oshirdi. O'rta ta'lim muassasalari duch keladigan eng muhim muammolardan biri maktab bitiruvchilariga o'zlarining akademik qobiliyatlari, uzoq muddatli natijalari va kasbiy kompetensiyalariga mos keladigan ta'lim yo'nalishlarini tanlashda yordam berishdir.

Ushbu tadqiqot o'n yillik davr davomida to'plangan uzoq muddatli akademik ko'rsatkichlar va Soft-Skills ko'nikmalar ko'rsatkichlarini tahlil qilish uchun mo'ljallangan mashinali o'rganishga asoslangan modellashtirish tizimini taklif qiladi. An'anaviy yondashuvlardan farqli o'laroq, taklif qilingan usul bir nechta akademik yillarni, o'rganishning rivojlanish tendentsiyalarini va kompetensiyaga bog'liq xususiyatlarni yagona bashoratli modelga birlashtiradi.

Oliy ta'limga kirayotgan talabalarning katta qismi ularning individual qobiliyatlari yoki kasbiy qiziqishlariga to'liq mos kelmaydigan akademik sohalarida tahsil olmoqda. Natijada, hatto ilg'or o'qitish metodologiyalarini qo'llash ham har doim ham yuqori malakali bitiruvchilarni tayyorlashni ta'minlamaydi.

ADABIYOTLAR TAHLILI.

So'nggi yillarda mashinali o'qitish algoritmlarini ta'lim tizimida qo'llash keng rivojlanib, o'quvchilarning akademik natijalarini bashorat qilish va ta'lim yo'nalishlarini aniqlashda samarali vosita sifatida qaralmoqda. Baker va Inventado tomonidan olib borilgan tadqiqotlarda ta'limiy ma'lumotlarni tahlil qilish orqali o'quvchilarning o'rganish xulq-atvorini aniqlash mumkinligi ko'rsatib berilgan [1]. Romero va Ventura esa Educational Data Mining yo'nalishining rivojlanishini tahlil qilib, mashinali o'qitish metodlari ta'lim tizimida qaror qabul qilish jarayonlarini optimallashtirishini ta'kidlaydi [2]. Klassik mashinali o'qitish algoritmlari, jumladan regressiya va tasniflash usullari, akademik natijalarni bashorat qilishda keng qo'llaniladi. Hastie va boshqalar regressiya modellari murakkab ma'lumotlar orasidagi bog'liqliklarni aniqlashda muhim rol o'ynashini ko'rsatadi [3]. Bishop esa probabilistik yondashuvlar orqali klassifikatsiya masalalarini samarali hal qilish mumkinligini asoslab beradi [4]. Chuqur o'rganish (deep learning) yondashuvlari ham ta'lim sohasida keng qo'llanilmoqda. Goodfellow va boshqalar neyron tarmoqlar murakkab va chiziqli bo'lmagan bog'lanishlarni aniqlashda yuqori aniqlik berishini ta'kidlaydi [5].

TADDIQOT METODOLOGIYASI.

Ushbu tadqiqotda ishlatilgan ma'lumotlar to'plami maktab o'quvchilarining o'n yillik davrdagi akademik yozuvlarini raqamlashtirish orqali yaratilgan. To'plangan ma'lumotlar fan bo'yicha baholar, yillik ishlash ko'rsatkichlari va akademik faoliyatda ishtirok etish, o'rganishning izchilligi va faollik darajasi kabi Soft-Skills ko'nikmalarni baholashni o'z ichiga oladi.

Yig'ilgan ma'lumotlarni raqamlashtirishdan so'ng, tegishli xususiyatlar keng qamrovli xususiyatlar matritsasini hosil qilish uchun ajratib olindi. Har bir o'quvchi uchun kirish vektori bir necha yillar davomida akademik ko'rsatkichlar, umumiy yutuqlar ballari va Soft-Skills ko'nikmalar ko'rsatkichlaridan iborat. Bu xususiyatlar talabalar faoliyatining ham kognitiv, ham kognitiv bo'lmagan jihatlarini birgalikda ifodalaydi. Masalan, $X = \{x_1, x_2, \dots, x_n\}$ o'quvchining xususiyat vektorini bildiradi, bu yerda n ajratib olingan xususiyatlar soni. Maqsadli o'zgaruvchi y – o'quvchiga tarixiy natijalar asosida berilgan ta'lim yo'nalishi toifasiga mos keladi.

Ko'p o'zgaruvchili regressiya va gradientga asoslangan optimallashtirish texnikalari ta'lim va muhandislik sohalarida bashoratli modellashtirish uchun keng qo'llaniladi. Akademik ko'rsatkichlar va ta'lim yo'nalishlari o'rtasidagi bog'liqlikni modellashtirish uchun ko'p o'zgaruvchili regressiya qo'llanildi. Chiziqli regressiya modeli quyidagicha ifodalanadi:

$$y = A_0 + \sum_{i=1}^n A_i \cdot x_i$$

Ta'lim yo'lini bashorat qilish uzluksiz qiymatni baholash o'rniga tasniflashni o'z ichiga olganligi sababli, chiziqli chiqish sigmasimon faollashtirish funktsiyasi yordamida o'zgartirildi:

$$\sigma(z) = \frac{1}{1 + e^{-z}}$$

Bu - regressiya chiqishini 0 va 1 oralig'idagi ehtimollik diapazonidir. Ushbu formula model chiqishlari yo'lining moslik ehtimoli sifatida talqin qilish imkonini beradi. Ko'p qatlamli perseptron arxitekturalari murakkab ta'lim ma'lumotlar to'plamlari ichida chiziqli bo'lmagan munosabatlarni aniqlashda yuqori natijalarni namoyish etdi.

$$J(A) = \frac{1}{m} \sum_{j=1}^m (y^{(j)} - \hat{y}^{(j)})^2$$

Bu yerda m o'quv namunalari sonini bildiradi. Har bir iteratsiya davomida A parametr vektori o'rganish tezligi α ga muvofiq yangilanadi va optimal yechimga bosqichma-bosqich yaqinlashishni ta'minlaydi.

Taklif etilgan modellarning ishlashi aniqlik, aniqlik, eslab qolish va F1 balli kabi standart tasniflash ko'rsatkichlari yordamida baholandi.

Ma'lumotlar to'plami umumlashtirish samaradorligini baholash uchun o'quv va sinov kichik guruhlariga bo'lindi. Ta'lim yo'llarini bashorat qilishda regressiyaga asoslangan modellar va neyron tarmoq arxitekturalarining samaradorligini baholash uchun qiyosiy tahlil o'tkazildi.

MUHOKAMA VA NATIJALAR.

Eksperimental natijalar shuni ko'rsatadiki, regressiyaga asoslangan modellar

barqaror boshlang'ich ko'rsatkichlarga erishadi va akademik ko'rsatkichlar orasidagi chiziqli munosabatlarni aniqlashda samaradorligini namoyish etadi. Biroq, neyron tarmoq modeli barcha baholash ko'rsatkichlari bo'yicha chiziqli yondashuvlardan doimiy ravishda ustun keldi. Ushbu yaxshilanish neyron tarmoqning uzoq muddatli akademik xususiyatlar orasidagi chiziqli bo'lmagan bog'lanishlar va o'zaro ta'sirlarni o'rganish qobiliyati bilan bog'liq bo'lishi mumkin.

Natijalar shuni tasdiqlaydiki, Soft-Skills ko'nikmalar ko'rsatkichlarini akademik baholar bilan birlashtirish modelning mustahkamligi va bashorat qilishning ishonchliligini oshiradi. Bu esa ta'lim yo'nalishini aniqlash faqat qisqa muddatli akademik natijalarga tayanish o'rniga talabalarining o'qish natijalarini yaxlit tarzda aks ettirishdan foyda ko'rishi haqidagi gipotezani qo'llab quvvatlaydi.

Taklif etilayotgan mashina o'qitish modeli ta'lim sohasidagi qarorlarni qabul qilish kontekstlarida amaliy qo'llanilishini namoyish etadi. Regressiyaga asoslangan modellar individual akademik xususiyatlarning ta'siri haqida qimmatli ma'lumotlarni taqdim etadi. Shu bilan birga, neyron tarmoq arxitekturalari yuqori bashoratli ishlashni taklif qiladi, bu ularni keng ko'lamli ta'limiy yo'naltirish tizimlarida joylashtirish uchun mos qiladi. Neyron tarmoq modeli regressiyaga asoslangan yondashuvlarga nisbatan yuqori natijalarni berdi.

Tadqiqotning bir qismi sifatida, mashinani o'qitish modellari 10 yil davomida 500 ta o'quvchidan to'plangan baholar va Soft-Skills ko'nikmalar ko'rsatkichlari asosida sinovdan o'tkazildi.

XULOSA VA TAKLIFLAR.

Maqolada maktab bitiruvchilarining uzoq muddatli akademik ko'rsatkichlari

va Soft-Skills ko'nikmalari ko'rsatkichlarini tahlil qilish orqali ta'lim yo'nalishlarini aniqlash uchun mashinaviy o'qitishga asoslangan model taqdim etilgan. Eksperimental natijalar shuni ko'rsatdiki, neyron tarmoq arxitekturasidan foydalanish an'anaviy qaror qabul qilish yondashuvlariga nisbatan ta'lim yo'nalishlarini bashorat qilishning aniqligini oshiradi.

Kelajakdagi ishlar qo'shimcha xulq-atvor va ijtimoiy-demografik omillarni o'z ichiga olgan ma'lumotlar to'plamini kengaytirishga, shuningdek, bashorat aniqligini yanada oshirish uchun ilg'or chuqur o'qitish arxitekturalarini o'rganishga qaratiladi. Taklif etilayotgan modelni real vaqt rejimida ta'limni boshqarish platformalariga integratsiya qilish mumkin.

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MAKTAB BITIRUVCHILARINING BOSHQA TA'LIM YO'NALISHINI BELGILASH UCHUN MASHINAVIY O'QITISH MODEL VA ARXITEKTURASI

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Anantatsiya. Zamonaviy ta'lim tizimida maktab bitiruvchilarining kelajak kasbiy faoliyati va ta'lim yo'nalishini to'g'ri tanlashi muhim strategik masalalardan biri hisoblanadi. An'anaviy kasbga yo'naltirish usullari asosan psixologik testlar, o'qituvchi tavsiyalari va shaxsiy qiziqishlarga asoslanadi. Biroq ushbu usullar ko'pincha subyektiv bo'lib, katta hajmdagi ma'lumotlarni tahlil qilish imkonini bermaydi. Shu sababli so'nggi yillarda ta'lim jarayonida sun'iy intellekt va mashinali o'qitish texnologiyalaridan foydalanish dolzarb ilmiy yo'nalishlardan biriga aylandi.

Kalit so'zlar: mashinali o'qitish, ta'lim analitikasi, kasbga yo'naltirish, sun'iy intellekt, klassifikatsiya algoritmlari, ta'lim yo'nalishi, ma'lumotlar tahlili.

I. Kirish

So'nggi yillarda global miqyosda ta'lim tizimini raqamlashtirish va sun'iy intellekt texnologiyalarini ta'lim jarayoniga joriy etish masalalari dolzarb ilmiy yo'nalishlardan biri bo'lib bormoqda. Zamonaviy jamiyatda iqtisodiy rivojlanish, innovatsiyalar va texnologik taraqqiyot ko'p jihatdan malakali kadrlar tayyorlash tizimining samaradorligiga bog'liqdir. Shu sababli maktab bitiruvchilarining kelajak kasbiy faoliyati va ta'lim yo'nalishini to'g'ri tanlash muammosi nafaqat pedagogik, balki iqtisodiy va ijtimoiy ahamiyatga ham ega [1].

Ko'plab mamlakatlarda maktab bitiruvchilarini kasbga yo'naltirish uchun turli metodologiyalar qo'llaniladi. Odatda bu jarayon psixologik testlar, o'qituvchilar tavsiyalari, ota-ona fikri hamda o'quvchilarning shaxsiy qiziqishlariga asoslanadi [2].

Biroq ushbu yondashuvlar ko'pincha subyektiv xarakterga ega bo'lib, o'quvchining haqiqiy qobiliyatlari va potensialini to'liq aks ettira olmaydi. Bundan tashqari, an'anaviy usullar katta hajmdagi ma'lumotlarni tizimli ravishda tahlil qilish imkoniyatini bermaydi [3].

Axborot texnologiyalarining jadal rivojlanishi ta'lim sohasida yangi ilmiy yo'nalish - Educational Data Mining va Learning Analytics kabi sohalarning paydo bo'lishiga olib keldi. Ushbu sohalarda o'quvchilar haqidagi katta hajmdagi ma'lumotlar tahlil qilinib, ularning o'qish jarayoni, qobiliyatlari va kelajakdagi muvaffaqiyati haqida prognozlar ishlab chiqiladi [4].

Mashinali o'qitish algoritmlari aynan shu jarayonlarda

muhim rol o'ynaydi. Mashinali o'qitish (Machine Learning) sun'iy intellektning muhim yo'nalishlaridan biri bo'lib, ma'lumotlar asosida model yaratish va kelajakdagi natijalarni prognozlash imkonini beradi [5]. Ushbu algoritmlar katta hajmdagi ma'lumotlardan yashirin qonuniyatlarni aniqlash va ular asosida qaror qabul qilish tizimlarini ishlab chiqishda keng qo'llaniladi [6].

II. Asosiy qism

Maktab bitiruvchilarining ta'lim yo'nalishlarini aniqlash jarayoni ko'p omilli va murakkab qaror qabul qilish muammosi hisoblanadi. Ushbu jarayonda o'quvchilarning akademik ko'rsatkichlari, qiziqishlari, shaxsiy qobiliyatlari va ijtimoiy omillar o'zaro bog'liq holda ta'sir ko'rsatadi. An'anaviy statistik yondashuvlar bunday ko'p o'zgaruvchili tizimlarni chuqur tahlil qilish imkoniyatini to'liq ta'minlamaydi. Shu sababli ushbu tadqiqotda maktab bitiruvchilarining ta'lim yo'nalishlarini aniqlash uchun mashinali o'qitish algoritmlariga asoslangan model ishlab chiqish metodologiyasi taklif etiladi. Tadqiqot metodologiyasi bir necha asosiy bosqichlardan iborat bo'lib, ular quyidagilarni o'z ichiga oladi:

1. Ma'lumotlar to'plamini shakllantirish, 2. Xususiyatlarni aniqlash (feature selection), 3. Ma'lumotlarni oldindan qayta ishlash (data preprocessing), 4. Mashinali o'qitish modelini tanlash, 5. Modelni o'qitish va baholash

Mazkur bosqichlar ta'lim analitikasi va mashinali o'qitish tizimlarida keng qo'llaniladigan metodologiyalarga asoslanadi [7].

Mashinali o'qitish algoritmlarining samaradorligi ko'p jihatdan foydalanilayotgan ma'lumotlar sifatiga bog'liq. Shu sababli tadqiqotda maktab bitiruvchilari haqidagi turli xil

ma'lumotlarni o'z ichiga olgan dataset shakllantiriladi. Ushbu ma'lumotlar bir nechta asosiy toifalarga ajratiladi: Akademik ko'rsatkichlarda o'quvchilarning asosiy fanlar bo'yicha baholari ta'lim yo'nalishini aniqlashda muhim omil hisoblanadi. Tadqiqotda quyidagi fanlar bo'yicha baholar hisobga olinadi:

- matematika, fizika, informatika, ona tili, chet tili, biologiya, tarix

Akademik ko'rsatkichlar o'quvchining qaysi sohada yuqori bilimga ega ekanligini aniqlash imkonini beradi [8].

O'quvchilarning ma'lum fanlarga qiziqish darajasi ham kasb tanlash jarayonida muhim rol o'ynaydi. Ushbu ko'rsatkichlar maxsus so'rovnomalar orqali aniqlanadi. Bu ko'rsatkichlar mashinali o'qitish modelida muhim xususiyatlar sifatida foydalaniladi. Zamonaviy ta'lim tizimida soft skills ham muhim ahamiyatga ega. Tadqiqotda quyidagi ko'nikmalar baholanadi:

- mantiqiy fikrlash, kommunikativ qobiliyat, ijodkorlik, muammolarni hal qilish qobiliyati, liderlik. Bu ko'rsatkichlar psixologik testlar va maxsus baholash metodlari orqali aniqlanadi [9].

Psixologik omillar - o'quvchilarning shaxsiy xususiyatlarini aniqlashga yordam beradi.

Masalan: analitik fikrlash, ijtimoiy faoliyat, texnik qiziqish, gumanitar qiziqish

Ushbu omillar kasb tanlash jarayoniga sezilarli ta'sir ko'rsatadi.

Mashinali o'qitish algoritmlarini tanlash: Tadqiqotda maktab bitiruvchilarining ta'lim yo'nalishlarini aniqlash uchun bir nechta mashinali o'qitish algoritmlaridan foydalanish taklif etiladi. Masalan, Logistik regresiya. U klassifikatsiya masalalarida keng qo'llaniladigan algoritm hisoblanadi. Ushbu model ehtimollik asosida ishlaydi. Logistik funksiyasi quyidagicha ifodalanadi:

$$P(y = 1|x) = \frac{1}{1 + e^{-z}}$$

bu yerda: $z = w_0 + w_1x_1 + w_2x_2 + \dots + w_nx_m$. Bu model o'quvchining ma'lum bir ta'lim yo'nalishini tanlash ehtimolini hisoblash imkonini beradi [10].

Random Forest algoritmi esa qaror daraxtlari asosida ishlaydigan jamlangan model hisoblanadi. Ushbu model bir nechta qaror daraxtlarining natijalarini birlashtirib yakuniy qaror qabul qiladi. Random Forest algoritmi yuqori aniqlik, ortiqcha moslashuvga chidamlilik va katta datasetlar bilan ishlash imkoniyati kabi afzalliklarga ega. Shu sababli ta'lim analitikasi masalalarida keng qo'llaniladi [11].

Natijalar.

Mazkur tadqiqotda maktab bitiruvchilarining ta'lim yo'nalishlarini aniqlash imkoniyatlarini baholash uchun sun'iy ma'lumotlar to'plami (synthetic dataset) shakllantirildi. Dataset 500 nafar o'quvchi haqidagi ma'lumotlarni o'z ichiga oladi. Har bir o'quvchi uchun akademik ko'rsatkichlar, qiziqish darajasi, soft skills ko'rsatkichlari va psixologik omillar hisobga olindi.

Dataset quyidagi asosiy atributlardan tashkil topgan:

matematika bahosi fizika bahosi, informatika bahosi, ona tili bahosi chet tili bahosi, mantiqiy fikrlash ko'rsatkichi, kommunikativ qobiliyat, ijodkorlik darajasi, texnik qiziqish darajasi.

Natijaviy o'zgaruvchi sifatida o'quvchining tanlashi mumkin bo'lgan ta'lim yo'nalishi ko'rib chiqildi. Tadqiqotda quyidagi asosiy yo'nalishlar belgilandi:

Axborot texnologiyalari, Muhandislik, Tibbiyot, Gumanitar fanlar.

Dataset mashinali o'qitish algoritmlari yordamidatahlil qilindi va turli klassifikatsiya modellarining natijalari solishtirildi.

Muhokama.

Mazkur tadqiqot natijalari mashinali o'qitish algoritmlaridan foydalanish maktab bitiruvchilarining ta'lim yo'nalishlarini aniqlash jarayonini sezilarli darajada takomillashtirish mumkinligini ko'rsatdi. Olingan natijalar shuni tasdiqlaydiki, o'quvchilarning akademik ko'rsatkichlari, fanlarga qiziqishi, soft skills ko'rsatkichlari va psixologik omillarni kompleks tahlil qilish orqali ta'lim yo'nalishlarini aniqroq prognozlash mumkin.

Tadqiqot davomida qo'llanilgan Logistic Regression, Random Forest va Support Vector Machine algoritmlari o'rtasida solishtirma tahlil o'tkazildi. Natijalar shuni ko'rsatdiki, Logistic Regression algoritmi boshqa modellar bilan solishtirganda yuqori aniqlik ko'rsatkichiga ega bo'ldi.

Ushbu algoritmnining asosiy afzalligi shundaki, u bir nechta qaror daraxtlarining natijalarini birlashtirib, ortiqcha moslashuv (overfitting) muammosini kamaytiradi va murakkab ma'lumotlar strukturasini samarali tahlil qilish imkonini beradi [6]

III. Xulosa

Mazkur tadqiqotda maktab bitiruvchilarining ta'lim yo'nalishlarini aniqlash jarayonida mashinali o'qitish algoritmlaridan foydalanish imkoniyatlari o'rganildi. Tadqiqot davomida o'quvchilarning akademik ko'rsatkichlari, fanlarga qiziqishi, soft skills va psixologik omillar asosiy xususiyatlar sifatida ko'rib chiqildi.

Olingan natijalar mashinali o'qitish algoritmlaridan foydalanish maktab bitiruvchilarining ta'lim yo'nalishlarini aniqlash jarayonini sezilarli darajada takomillashtirish mumkinligini ko'rsatdi. Tadqiqot natijalariga ko'ra Logistic Regression algoritmi boshqa modellar bilan solishtirganda yuqori aniqlik ko'rsatkichiga ega ekanligi aniqlandi. Tadqiqot natijalari quyidagi xulosalarni shakllantirish imkonini berdi:

mashinali o'qitish algoritmlari o'quvchilarning qobiliyatlari va qiziqishlarini kompleks tahlil qilish imkonini beradi;

akademik ko'rsatkichlar, ayniqsa matematika va informatika fanlari texnik yo'nalishlarni tanlashda muhim omil hisoblanadi;

soft skills ko'rsatkichlari gumanitar yo'nalishlarni aniqlashda muhim rol o'ynaydi;

mashinali o'qitish asosida kasbga yo'naltirish tizimini avtomatlashtirish mumkin.

Taklif etilgan yondashuv ta'lim muassasalarida intellektual kasbga yo'naltirish tizimlarini yaratish uchun ilmiy asos bo'lib xizmat qilishi mumkin. Ushbu tizim o'quvchilarning qobiliyatlari va qiziqishlarini hisobga olgan holda ularga mos ta'lim yo'nalishlarini tavsiya etishga yordam beradi.

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STOMATOLOGIK MA'LUMOTLARGA DASTLABKI ISHLOV BERISHNING MATEMATIK VA DASTURIY TA'MINOTINI ISHLAB CHIQISH

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Annotatsiya. Maqolada stomatologik ma'lumotlarga dastlabki ishlov berish masalasi ko'rib chiqilgan. Tasvir sifatini yaxshilash, shovqinni kamaytirish va kontrastni oshirish maqsadida median filtri, Gauss filtri hamda histogram tenglashtirish usullaridan foydalanilgan. Ushbu algoritmlar asosida rentgen tasvirlarning sifat ko'rsatkichlari tahlil qilinib, ishlov berish samaradorligi baholangan. Natijada tasvirlardagi shovqin darajasi kamaygani va aniqlik sezilarli darajada oshgani aniqlangan.

Kalit so'zlar: stomatologik rentgen tasvirlar, image preprocessing, noise reduction, contrast enhancement, median filtering, Gaussian filtering, histogram equalization, mathematical modeling

Kirish. Stomatologik tashxis qo'yish jarayonida rentgen tasvirlardan foydalanish keng tarqalgan bo'lib, ular asosida kasalliklarni aniqlash va baholash amalga oshiriladi. Biroq, rentgen tasvirlarda shovqinlarning mavjudligi, kontrastning pastligi hamda tasvir sifatining yetarli emasligi diagnostika aniqligiga salbiy ta'sir ko'rsatadi. Shu sababli, tasvirlarga dastlabki ishlov berish (image preprocessing) usullaridan foydalanish tasvir sifatini oshirish va keyingi tahlil jarayonlarini samarali tashkil etishda muhim ahamiyatga ega.

Zamonaviy tasvirga ishlov berish usullari yordamida rentgen tasvirlarning sifat ko'rsatkichlarini yaxshilash, shovqinni kamaytirish va muhim diagnostik belgilarni ajratib olish mumkin. Ushbu maqsadda keng qo'llaniladigan samarali preprocessing usullari quyidagilar hisoblanadi:

1.Filtering usullari (Median filtering va Gaussian filtering) – ushbu usullar tasvirdagi shovqinni kamaytirishga xizmat qiladi. Median filtering impulsli shovqinlarni samarali bartaraf etadi, Gaussian filtering esa tasvirni silliqlash orqali umumiy shovqin darajasini pasaytiradi. Bu usullar tasvir sifati past bo'lgan holatlarda qo'llash uchun maqsadga muvofiq.

2.Histogram equalization – bu usul tasvir kontrastini oshirishga yordam beradi. Tasvirdagi yorqinlik darajalarini qayta taqsimlash orqali muhim obyektlar yanada aniq ko'rinishga ega bo'ladi. Ushbu yondashuv past kontrastli tasvirlarda samarali hisoblanadi.

3.Image normalization va scaling – bu usullar tasvir piksel qiymatlarini standart diapazonga keltirish orqali keyingi ishlov berish bosqichlari uchun qulay sharoit yaratadi. Ayniqsa, turli manbalardan olingan tasvirlar bilan ishlashda muhim ahamiyatga ega.

4.Edge detection (chegara aniqlash) – tasvirdagi obyektlarning chegaralarini aniqlashga yordam beradi. Bu usul diagnostik jihatdan muhim elementlarni ajratishda qo'llaniladi.

Xulosa. Yuqorida ko'rib chiqilgan usullardan foydalanib, stomatologik rentgen tasvirlarga dastlabki ishlov berish masalasi hamda tasvir sifatini yaxshilashga qaratilgan asosiy usullar o'rganildi. Xususan, median filtering va Gaussian filtering yordamida tasvirlardagi shovqin darajasini kamaytirish, histogram equalization orqali esa kontrastni oshirish imkoniyati ko'rsatib berildi.

O'tkazilgan tahlillar natijasida mazkur preprocessing usullarining qo'llanilishi rentgen tasvirlarning sifat ko'rsatkichlarini sezilarli darajada yaxshilashi va diagnostik aniqlikni oshirishga xizmat qilishi ko'rsatib berildi. Shuningdek, ushbu yondashuvlar keyingi bosqichlarda tasvirlarni tahlil qilish va avtomatlashtirilgan diagnostika tizimlarini ishlab chiqishda samarali asos bo'lib xizmat qilishi mumkin.

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SUN'IY INTELLEKT ASOSIDA QANDLI DIABETNI ERTA ANIQLASH TIZIMINI ISHLAB CHIQISH

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ANNOTATSIYA

Ushbu maqolada sun'iy intellekt va zamonaviy veb-texnologiyalar yordamida qandli diabetni erta bosqichda aniqlashga mo'ljallangan dasturiy tizim ishlab chiqish jarayoni yoritiladi. Taqdim etilayotgan tizim Random Forest klassifikatsiya algoritmi asosida qurilgan bo'lib, bemorning yoshi, tana massasi indeksi, qondagi qand miqdori, qon bosimi, oilaviy tarix va jismoniy faollik ko'rsatkichlarini tahlil qilgan holda qandli diabet xavfini foiz ko'rinishida hisoblaydi. Ushbu tadqiqotning asosiy maqsadi qandli diabet xavfini real vaqt rejimida aniq va tez bashorat qiluvchi, foydalanuvchiga qulay interaktiv veb interfeysi bo'lgan, O'zbek tilidagi sun'iy intellekt asosidagi tibbiy diagnostika tizimini ishlab chiqishdan iborat. Amaliy ahamiyati jihatidan ushbu tizim birlamchi tibbiy ko'rik punktlarida, oilaviy klinikalarda va profilaktika dasturlarida qo'llash uchun mos. Shifokorlar uchun qo'shimcha qaror qabul qilish vositasi, bemorlar uchun esa o'z-o'zini tekshirish imkonini beruvchi platforma sifatida xizmat qilishi mumkin.

Kalit so'zlar: sun'iy intellekt, qandli diabet, Random Forest, FastAPI, machine learning, tibbiy diagnostika, veb-ilova, sintetik dataset, risk bashorati.

1. KIRISH

Mashinaviy o'qitish metodlarining tibbiy diagnostikada qo'llanilishi so'nggi o'n yil ichida jadal rivojlandi. Kavakiotis va boshqalar tomonidan 2017-yilda o'tkazilgan keng qamrovli meta-tahlil 85 ta tadqiqot natijalarini umumlashtirib, quyidagi algoritmlarning qandli diabet diagnostikasidagi o'rtacha aniqlik ko'rsatkichlarini aniqladi [1].

Random Forest va XGBoost algoritmlari tibbiy diagnostikada eng yuqori ko'rsatkichlarga ega. Biroq XGBoostga nisbatan Random Forestning asosiy ustunligi uning giperpametrlarga nisbatan kamroq sezgir ekanligi va talqin qilishning soddaligidir. Bu xususiyat klinik muhitda ishonchlilik va shaffoflik talab qilingan hollarda muhim ahamiyat kasb etadi [2].

2. METODOLOGIYA

Ishlab chiqilgan tizim uch asosiy qatlamdan iborat bo'lib, ular o'rtasida aniq belgilangan interfeyslar orqali ma'lumot almashinuvi amalga oshiriladi. Bu uch qatlamli arxitektura bir nechta muhim afzalliklarni ta'minlaydi. Birinchidan, har bir qatlam mustaqil rivojlantirilishi va alohida sinovdan o'tkazilishi mumkin. Ikkinchidan, ML modeli yangilanganda frontend va backendda hech qanday o'zgarish talab qilinmaydi [3]. Uchinchidan, tizimni gorizontal kengaytirish imkoni yaratiladi.

3. NATIJALAR VA MUHOKAMA

Model sinov to'plamida quyidagi ko'rsatkichlarga erishdi. Sezgirlik ko'rsatkichi tibbiy diagnostikada ayniqsa muhim [4]. U haqiqiy kasallardan necha foizini tizim aniqlay olishini ko'rsatadi. 82–88% Recall qiymati klinik amaliyot uchun qabul qilingan bo'lib, bu qiymatni oshirish keyingi ishlar uchun asosiy maqsadlardan biri sifatida belgilangan. ROC-AUC ko'rsatkichi 0.92–0.96 darajasi modelning yaxshi differentsiatsiya qobiliyatiga ega ekanligini tasdiqlaydi. 0.5 qiymat tasodifiy bashorat, 1.0 esa mukammal bashoratga to'g'ri keladi. 0.92+ qiymat klinik foydalanish uchun mos deb hisoblanadi.

4. XULOSA

Ushbu tadqiqotda qandli diabetni erta aniqlashga mo'ljallangan, sun'iy intellekt asosidagi to'liq funksional veb-tizim muvaffaqiyatli ishlab chiqildi va quyidagicha natijalarga erishildi:

Random Forest modeli 6 ta klinik ko'rsatkich asosida 88–92% aniqlikda va 0.92–0.96 ROC-AUC ko'rsatkichida bashorat beradi. Bu klinik amaliyot uchun qabul qilingan me'yor;

FastAPI backend 50 millisekunddan kam javob vaqtida ishlaydi, bu real vaqtda tibbiy qaror qabul qilish uchun yetarli;

O'zbek tilidagi interaktiv interfeys tibbiy AI texnologiyalarni mahalliy foydalanuvchiga yaqinlashtiradi va tibbiy savodxonlikni oshirishga hissa qo'shadi;

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TIBBIY AXBOROT MODELINING MATEMATIK TA'MINOTI

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Annotatsiya. Ushbu maqolada sun'iy intellekt texnologiyalariga asoslangan tibbiy axborot modelinining matematik ta'minotini ishlab chiqish masalasi ko'rib chiqilgan. Qo'yilgan masalani hal qilish maqsadida matematik ta'minotning sxematik ko'rinishi ishlab chiqilgan va uning tashkil etuvchilari tavsiflangan. Shuningdek avtomatlashtirilgan tashxis qilish tizimlaridan foydalanish bo'yich bir qator tavsiylar keltirilgan.

Kalit so'zlar: mashinali o'rganish, statistik modellar, qaror daraxtlari, noan'naviy bo'lmagan mantiq, matematik ta'minot.

Tibbiy tadqiqotlar sohasida tashxis qilish uchun matematik modellarni ishlab chiqish katta istiqbolga ega bo'lib, bemorlarni davolash natijalarini sezilarli darajada yaxshilash va tibbiyot sohasidagi yutuqlarni ilgarilantirish imkoniyatini taqdim etadi. Tibbiy tashxis qilishning avtomatlashtirilgan tizimlari uchun mo'ljallangan ushbu matematik modellar mashinali o'rganish algoritmlari, statistik modellar va qaror qabul qilish daraxtlari kabi turli usullarni o'z ichiga oladi[1]. Ularning asosiy maqsadi bemor ma'lumotlarini, jumladan, kasallik tarixi, alomatlar, yosh va boshqa tegishli ma'lumotlarni hisobga olgan holda atroflicha tahlil qilish va aniq tashxis qo'yishdir. Tibbiy tadqiqotlarga matematik yondashuvni integratsiya qilish tibbiy tashxis muammolarni hal qilish uchun yangi yo'nalishlarni ochadi. Turli kasalliklarni tashxislash jarayonida odatda ketma-ket va mantiqiy qurilgan yondashuv qo'llaniladi, ko'pincha tibbiy mantiqqa moslashtirilgan matematik modellardan foydalanadigan tashxis qilish algoritmlari qo'llaniladi. Ayniqsa, noqatiy to'plamlar nazariyasi usullaridan foydalanish ushbu yondashuvning tashxis qilish va bashorat qilish uchun axborot-matematik modellar yaratishdagi potentsialini namoyish etadi.

Kasallik tashxisi sohasida Naive Bayes algoritmlari elektron sog'liqni saqlash yozuvlari yoki tibbiy hisobotlardan foydalangan holda qo'llaniladi. Ushbu algoritmlar matn ichida uchraydigan alomatlar asosida ma'lum bir tashxis ehtimolini hisoblash uchun Bayes teoremasidan foydalanadi [2]. Bu yondashuv matnli tibbiy ma'lumotlardan kasalliklarni avtomatik aniqlashga yordam beradi.

Kasalliklarni tashxislash uchun matematik model ishlab chiqish. An'naviy bo'lmagan mantiq va qaror qabul qilish usullaridan foydalangan holda, model tashxis qilish belgilarning aniq bo'lmagan va noaniq tabiatini hisobga olishi va ularni ekspert bilimlari bilan birlashtirib, aniq va ishonchli tashxis qo'yishi mumkin. Bunday modelni ishlab chiqish uchun quyidagi bir qator qadamlar tashlandi:

Ushbu sxema 7 ta qismdan iborat bo'lib, ma'lumot oqimini tasvirlaydi:

Kirish — tizimga bemor simptomlari, laboratoriya natijalari va anamnez ma'lumotlari uzatiladi.

Fuzzifikatsiya — aniq raqamli qiymatlar "past / o'rta / yuqori" kabi noqatiy (kategorik) to'plamlarga o'tkaziladi. Sxemada uch xil tegishlilik funksiyasi (uchburchak, trapetsiya, Gauss) ko'rsatilgan.

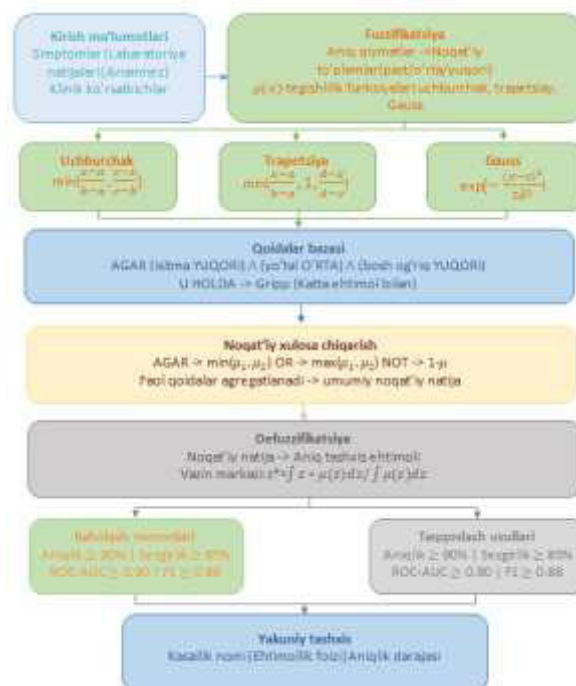
Qoidalar bazasi — ekspert bilimlar asosida "AGAR...U HOLDA" shaklidagi qoidalar qo'llaniladi.

Noqatiy xulosa — AND, OR, NOT mantiqiy amallar yordamida bir nechta qoida birgalikda baholanadi va agregatlanadi.

Defuzzifikatsiya — noqatiy natija aniq son (ehtimollik foizi) ko'rinishida ifodalanadi.

Baholash va taqqoslash — model aniqlik, sezgirlik, ROC-AUC mezonlariga ko'ra baholanadi va boshqa usullar bilan taqqoslanadi.

Yakuniy tashxis — kasallik nomi, ehtimollik foizi va ishonchlilik darajasi chiqadi.



1-rasm. Matematik modelning sxematik tasviri

Avtomatlashtirilgan tashxis qilish tizimlari ushbu matematik modeldan samarali foydalanishi mumkin. Bunday tizimlarni joriy etish shifokorlarning professional qobiliyatlarini sezilarli darajada oshiradi, ularga ilg'or tibbiy tashxis vositalari va usullaridan foydalanish imkonini beradi. Turli bemor ma'lumotlarini integratsiya qilish, ilg'or mashinali o'rganish usullari va uzoq muddatli tahlillar orqali sog'liqni saqlash mutaxassislari individuallashtirilgan davolashni rejalashtirish, erta aralashuv va resurslarni taqsimlashda yordam beradigan bashorat modellarini ishlab chiqishlari mumkin [3]. Sog'liqni saqlash xizmat ko'rsatuvchilari ma'lumotlarga asoslangan bashoratlarning kuchidan foydalanib bemorlar natijalarini yaxshilash va sog'liqni saqlash xizmatlarini samaraliroq taqdim etishga intilishlari mumkin. Bashorat modellari bu jarayonda mavjud ma'lumotlardan foydalanish va algoritmlarni qo'llash orqali kasallikning rivojlanishini turli aniqlik darajalarida baholash orqali hal qiluvchi rol o'ynaydi.

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MODELS AND ALGORITHMS FOR VISUALIZATION OF ULTRASOUND MEDICAL DATA- FIBROMA IMAGES

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Abstract. Uterine fibroids are among the most common gynaecological problems in women of reproductive age, yet monitoring how they change over time still relies heavily on manual comparison of images across visits. This paper presents a software system that takes standard B-mode ultrasound images, removes speckle noise, finds the fibroid boundary with an active contour model, extracts shape and texture measurements, and feeds them into a K-Nearest Neighbour (KNN) classifier to assign one of three clinical severity grades.

Keywords: *uterine fibroid, ultrasound segmentation, KNN classification, active contour, geometric modelling, dynamic monitoring*

1. INTRODUCTION

Benign uterine tumours — fibroids, myomas, or leiomyomas — affect up to 74 % of premenopausal women when tissue is examined histologically [1]. Most cases are silent, but a substantial share cause heavy periods, pelvic pain, bladder pressure, and fertility problems. One in five referrals to a gynaecology outpatient clinic in some health systems is fibroid-related [2], and the economic burden is considerable.

Ultrasonography is the standard diagnostic tool: portable, inexpensive, and free of ionising radiation. Its weakness is image quality. Speckle noise blurs fibroid margins and makes it hard to track subtle size changes reliably from one visit to the next. Sonologists currently trace boundaries by hand, record dimensions in a report, and start from scratch when the patient attends a different clinic. Our system was built to replace that fragmented workflow with an automated, database-linked pipeline that accumulates a fibroid's full measurement history across every visit.

2. METHODS

The pipeline has four stages — preprocessing, segmentation, feature extraction, and classification — each feeding directly into the next (Figure 1).

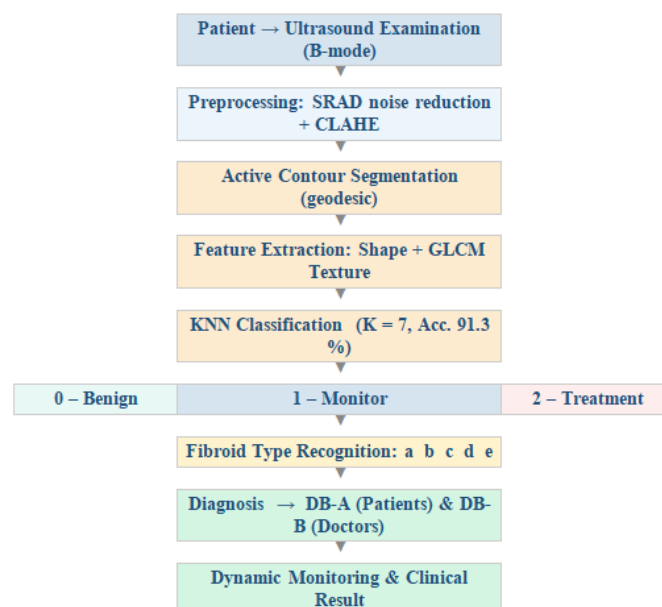


Figure 1. Processing pipeline: from ultrasound acquisition to dynamic fibroid monitoring

Preprocessing. Raw B-mode frames pass through Speckle-Reducing Anisotropic Diffusion (SRAD), which smooths homogeneous regions while keeping edges sharp. Contrast-Limited

Adaptive Histogram Equalisation (CLAHE) is then applied locally to improve the visibility of the fibroid margin against the surrounding myometrium.

Segmentation. A geodesic active contour (level-set snake) is initialised near the fibroid centre and deformed to minimise: $E(C) = \int [\alpha|C'|^2 + \beta|C''|^2] ds + \lambda \int g(|\nabla I|) ds$, where α and β control smoothness, λ weights the image force, and g falls to zero at strong edges. Operating on the pre-processed image stabilises convergence at low-contrast boundaries.

Feature extraction. Two feature families are computed from the segmented region: geometric measures (area, perimeter, circularity, eccentricity) and Grey-Level Co-occurrence Matrix (GLCM) texture descriptors (contrast, energy, correlation, homogeneity).

KNN classification. Feature vectors are min-max normalised and compared to training examples by Euclidean distance. The majority label among the K nearest neighbours determines the severity class: 0 (benign, no action), 1 (monitor), or 2 (refer for treatment). Five-fold cross-validation identified $K = 7$ as the most stable setting. Fibroids are also tagged by anatomical location: subserosal (a), submucosal (b), pedunculated (c), intramural (d), or intracavitary (e).

3. RESULTS

The dataset comprised 420 ultrasound studies from 280 women (Tashkent, 2019–2023), acquired at 3.5–7.5 MHz with transabdominal and transvaginal probes. Two sonologists annotated boundaries independently (inter-observer Dice = 0.87). The split was 70 % training, 15 % validation, 15 % test. Segmentation averaged a Dice score of 0.84 ± 0.06 on the test set.

K Value	Accuracy	Precision	Recall	F1-Score
K = 3	86.2 %	84.7 %	83.9 %	84.3 %
K = 5	89.4 %	88.1 %	87.6 %	87.8 %
K = 7 ✓	91.3 %	90.5 %	89.8 %	90.1 %
K = 9	90.1 %	89.2 %	88.4 %	88.8 %
K = 11	88.7 %	87.3 %	86.9 %	87.1 %

Table 1. KNN classification performance by K value (✓ = selected setting, highlighted)

Performance peaks at $K = 7$ (accuracy 91.3 %, precision 90.5 %, recall 89.8 %, F1 90.1 %), then declines slightly for larger K . Against four alternatives on the same feature set — active contour alone (83.1 %), level-set method (86.7 %), SVM (87.5 %), and Random Forest (88.2 %) — KNN at $K = 7$ is the most accurate and the fastest at inference time.

4. DISCUSSION

A 91 % accuracy figure is useful, but clinical adoption depends on trust and usability. KNN earns trust through transparency: when it assigns grade 2, it can display the seven most similar training cases alongside their recorded outcomes, giving the clinician a concrete basis for agreement or challenge — something opaque models cannot offer. The dual-database design proved equally important in practice. Database A stores patient demographics, symptoms, and treatment history; Database B stores sonologist annotations and system measurements keyed to each examination. Linking both to a shared patient identifier means any clinician can instantly retrieve a patient's complete fibroid history, regardless of where previous examinations took place. In pilot use this removed the need to repeat measurements and made multi-year growth curves straightforward to generate.

5. CONCLUSION

We have described a practical system for automated fibroid monitoring that combines speckle reduction, active contour segmentation, and KNN classification in a single pipeline backed by a longitudinal patient database. At $K = 7$ the classifier achieves 91.3 % accuracy, outperforming four established alternatives, while the interpretable nearest-neighbour mechanism and the persistent dual-database make it suitable for real clinical use. Future work will extend validation to multiple centres, explore three-dimensional reconstruction, and investigate hybrid segmentation using neural networks at the boundary-finding stage while retaining KNN's interpretability for the final grading decision.

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O‘SMIRLARDA SUT BEZI SARATONI KASALLIGINI ERTA ANIQLASHDA INFORMATIV BELGILAR MAJMUASINI TA’MINLASH ALGORITMI VA DASTURIY VOSITASINI ISHLAB CHIQISH

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Annotatsiya

Mazkur tezisda o‘smirlarda sut bezi saratoni kasalligini erta bosqichlarda aniqlash uchun informativ belgilar majmuasini shakllantirish, ularni tahlil qiluvchi algoritm yaratish hamda dasturiy vosita ishlab chiqish masalalari yoritilgan. Tadqiqot davomida klinik simptomlar, diagnostik ko‘rsatkichlar va tibbiy ma‘lumotlar asosida intellektual tahlil modeli taklif qilindi. Ishlab chiqilgan dasturiy vosita kasallik xavfini dastlabki bosqichlarda aniqlash va diagnostika jarayonini avtomatlashtirish imkonini beradi.

Kalit so‘zlar: sut bezi saratoni, erta diagnostika, algoritm, dasturiy vosita, informativ belgilar, sun‘iy intellekt, tibbiy axborot tizimi.

Bugungi kunda inson salomatligini muhofaza qilish va xavfli kasalliklarni erta aniqlash dunyo tibbiyotining eng muhim yo‘nalishlaridan biri hisoblanadi. Ayniqsa, onkologik kasalliklar orasida sut bezi saratoni kasalligi keng tarqalgan bo‘lib, u ayollar salomatligiga jiddiy xavf tug‘diradi. So‘nggi yillarda ushbu kasallikning yoshlar, jumladan o‘smirlar orasida uchrash holatlari ham kuzatilmoqda. Kasallikning dastlabki bosqichlarida aniq klinik belgilar sezilmasligi esa uni o‘z vaqtida aniqlashni murakkablashtiradi. Shu sababli sut bezi saratonini erta diagnostika qilish masalasi zamonaviy tibbiyotning dolzarb muammolaridan biri sifatida qaralmoqda.

Axborot-kommunikatsiya texnologiyalarining rivojlanishi tibbiyot sohasida ham yangi imkoniyatlarni yuzaga keltirdi. Xususan, sun‘iy intellekt, ma‘lumotlar bazasi texnologiyalari, mashinaviy o‘qitish va avtomatlashtirilgan tahlil tizimlari yordamida kasalliklarni aniqlash samaradorligini oshirish imkoniyati paydo bo‘ldi. Tibbiy ma‘lumotlarni raqamli qayta ishlash orqali simptomlar va diagnostik ko‘rsatkichlarni tezkor tahlil qilish mumkin bo‘lmoqda. Natijada shifokor faoliyatini qo‘llab-quvvatlovchi, diagnostika jarayonida inson omili bilan bog‘liq xatoliklarni kamaytiruvchi dasturiy tizimlarni yaratishga bo‘lgan ehtiyoj ortmoqda.

Sut bezi saratonini aniqlashda kasallikning informativ belgilarini to‘g‘ri tanlash muhim ahamiyatga ega. Bunday belgilar yordamida bemorning holatini baholash, xavf darajasini aniqlash va dastlabki tashxislarni qo‘yish mumkin bo‘ladi. Ayniqsa, o‘smirlar organizmida fiziologik o‘zgarishlar faol kechishi sababli kasallik simptomlarini oddiy holatlardan farqlash murakkab hisoblanadi. Shu sababli tibbiy belgilarni tizimli ravishda tahlil qiluvchi algoritm ishlab chiqish muhim ilmiy-amaliy ahamiyat kasb etadi.

Sut bezi saratonini erta aniqlash va diagnostika jarayonlarini avtomatlashtirish bo‘yicha ko‘plab xorijiy olimlar ilmiy izlanishlar olib borgan. Xususan, Vikash Deendyal, Lilit Ghazaryan, Erica Linden va Nikhil G. Thaker tomonidan olib borilgan tadqiqotlarda sun‘iy intellekt

texnologiyalarining mammografiya va ultratovush tasvirlarini tahlil qilishdagi samaradorligi yoritilgan. Ularning ilmiy ishlarida chuqur o'qitish algoritmlarining kasallikni aniqlash aniqligini oshirishi ko'rsatib o'tilgan.

Rolando Gonzales Martinez va D.M. van Dongen tomonidan amalga oshirilgan tadqiqotlarda chuqur o'qitish texnologiyalarining an'anaviy mashinaviy o'qitish usullariga nisbatan samaraliroq ekani asoslab berilgan. Tadqiqot natijalariga ko'ra, neyron tarmoqlar asosida ishlovchi tizimlar tibbiy tasvirlarni tezkor tahlil qilish imkoniyatiga ega.

Panagiota Karatza va hamkorlari tomonidan olib borilgan izlanishlarda interpretatsiyalanuvchi sun'iy intellekt modellarining sut bezi saratoniga tashxis qo'yishdagi samaradorligi o'rganilgan. Tadqiqotda Random Forest va neyron tarmoq algoritmlarining natijalari taqqoslangan.

Ali Bou Nassif va boshqa tadqiqotchilar tomonidan amalga oshirilgan ilmiy ishlarda esa sun'iy intellekt asosidagi diagnostika tizimlarining kasallikni erta aniqlashdagi o'rni tahlil qilingan. Ularning tadqiqotlari gistopatologik tasvirlarni qayta ishlash orqali yuqori aniqlikdagi diagnostika natijalariga erishish mumkinligini ko'rsatgan.

Yuqoridagi ilmiy ishlardan farqli ravishda ushbu tadqiqotda o'smirlarda uchrashi mumkin bo'lgan sut bezi saratoni kasalligini klinik belgilar asosida baholash va foydalanuvchi ma'lumotlarini avtomatik qayta ishlovchi dasturiy vosita yaratishga asosiy e'tibor qaratildi. Tadqiqotning asosiy maqsadi o'smirlarda sut bezi saratoni kasalligini erta aniqlashga yordam beruvchi informativ belgilar majmuasini shakllantirish hamda ushbu belgilar asosida ishlovchi algoritmi va dasturiy vosita yaratishdan iborat. Mazkur maqsadni amalga oshirish jarayonida kasallikning asosiy simptomlari, diagnostik ko'rsatkichlari va xavf omillari o'rganildi. Shuningdek, foydalanuvchi ma'lumotlarini tahlil qilish va dastlabki diagnostik xulosa chiqarish imkoniyatiga ega tizim modelini ishlab chiqish amalga oshirilmoqda.

Tadqiqot davomida sut bezi saratonini aniqlashda muhim ahamiyatga ega bo'lgan klinik belgilar tanlab olindi. Ular qatoriga sut bezida zichlashgan qismning paydo bo'lishi, og'riq hissi, bez shaklining o'zgarishi, teri yuzasidagi tortilish yoki qizarish holati, limfa tugunlarining kattalashuvi, irsiy moyillik va ultratovush tekshiruvi natijalari kiritildi. Har bir belgi tizimda ma'lum diagnostik qiymat asosida baholanadi va umumiy xavf ko'rsatkichi shakllantiriladi. Belgilar o'rtasidagi bog'liqlikni aniqlash orqali kasallik ehtimolini dastlabki bosqichlarda prognoz qilish imkoniyati yaratiladi.

Taklif etilgan algoritmi foydalanuvchi ma'lumotlarini qabul qilish, simptomlarni tahlil qilish, diagnostik ko'rsatkichlarni qayta ishlash hamda xavf darajasini aniqlash bosqichlaridan iborat. Algoritmi asosida ishlab chiqilgan dasturiy vosita foydalanuvchiga qulay interfeys orqali ma'lumotlarni kiritish va avtomatik natijalarni olish imkonini beradi.

Dasturiy vosita simptomlarni baholash orqali foydalanuvchining xavf darajasini aniqlaydi va tavsiya shakllantiradi. Tizimdan tibbiyot muassasalari, profilaktika markazlari hamda diagnostika jarayonida yordamchi vosita sifatida foydalanish mumkin.

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BOSH MIYA SARATONI TASVIRLI MA'LUMOTLARINI KLASSTERLASHNING NAZARIY ASOSLARI

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Abstract

Ushbu ishda bosh miya saratoni tasvirli ma'lumotlarini klasterlashning nazariy asoslari o'rganildi. Tadqiqot doirasida MRI tasvirlarni tahlil qilishda qo'llaniladigan asosiy usullar, jumladan K-means, Fuzzy C-Means (FCM), Convolutional Neural Network (CNN) va Support Vector Machine (SVM) algoritmlari ko'rib chiqildi.

Tahlil natijalariga ko'ra, klasterlash algoritmlari segmentatsiya jarayonida samarali bo'lsa-da, mashinaviy o'qitish va chuqur o'rganish usullari yuqori aniqlikni ta'minlashi aniqlandi. Shuningdek, tasvirni oldindan qayta ishlash va bir nechta usullarni birgalikda qo'llash natijalarni yaxshilashi kuzatildi.

Olingan natijalar bosh miya saratonini aniqlashda zamonaviy yondashuvlarning muhim ahamiyatga ega ekanligini ko'rsatadi.

Kalit so'zlar: bosh miya saratoni, MRI tasvirlar, klasterlash, K-means, Fuzzy C-Means (FCM), sun'iy intellekt, CNN, SVM, segmentatsiya, klassifikatsiya.

Adabiyotlar tahlili

So'ngi yillarda bosh miya o'smalarini aniqlashda klasterlash va sun'iy intellekt usullari keng qo'llanilmoqda. Bhimavarapu U., Chintalapudi N., Battineni G.(2024) tomonidan MRI tasvirlari asosida bosh miya o'smalarini aniqlash uchun takomillashtirilgan Fuzzy C-Means klasterlash va mashinaviy o'qitish usulini taklif qilishgan. Abdel-Maksoud E., Elmogy M., (2015) va boshqalar esa K-means va Fuzzy C-Means algoritmlarini birlashtirish orqali bosh miya o'smalarini segmentatsiya qilishning samarali usuli ishlab chiqqanlar.

Shuningdek, Khan H.A., Wu J., va boshqalar (2020) CNN (chuqur o'rganish) yordamida MRI tasvirlardan bosh miya o'smalarini aniqlash va klassifikatsiya qilish usuli ko'rib chiqilgan bo'lib, yuqori aniqlik ko'rsatkichlariga erishganlar. Haldar va boshqalar (2023) esa K-means klasterlash yordamida o'smalarni radiomik xususiyatlariga qarab guruhlariga ajratgan. Bundan tashqari, Alqhtani va boshqalar (2024) FCM va SVM algoritmlarini qo'llab, o'smalarni aniqlash va tasniflashning samarali modelini taklif etgan. Shuningdek, Asiri va boshqalar (2024) tomonidan MRI tasvirlarni yaxshilash va SVM asosida klassifikatsiya qilishning ikki bosqichli modeli ishlab chiqilgan bo'lib, yuqori aniqlik ko'rsatkichlariga erishilgan.

Kirish

Hozirgi kunda bosh miya saratoni inson salomatligiga jiddiy xavf tug'diruvchi kasalliklardan biri hisoblanadi. Ushbu kasallikni erta aniqlash va to'g'ri tashxis qo'yish bemor hayotini saqlab qolishda muhim ahamiyat kasb etadi. Tibbiyot sohasida magnit-rezonans tomografiya (MRI) keng qo'llanilib, u bosh miya tuzilishini aniq tasvirlash imkonini beradi.

Shu bilan birga, MRI tasvirlarni tahlil qilish jarayoni murakkab bo'lib, tasvirlarda shovqinlarning mavjudligi, kontrast darajasining pastligi hamda o'smalarning turli shakl va o'lchamlarda bo'lishi aniqlash jarayonini qiyinlashtiradi. Natijada, an'anaviy usullar har doim ham yuqori aniqlikni ta'minlay olmaydi.

So'nggi yillarda ushbu muammoni hal etishda klasterlash algoritmlari va zamonaviy hisoblash usullaridan foydalanishga katta e'tibor qaratilmoqda. Bu yondashuvlar tasvirlarni avtomatik ravishda tahlil qilish va o'smalarni aniqlash samaradorligini oshirish imkonini beradi.

Ushbu ishning maqsadi bosh miya saratoni tasvirli ma'lumotlarini klasterlashning nazariy asoslarini o'rganish hamda mavjud usullarni tahlil qilishdan iborat.

Metodlar.

Bosh miya saratoni MRI tasvirlarini tahlil qilishda bir nechta klasterlash va mashinaviy o'qitish algoritmlaridan foydalaniladi. Eng ko'p qo'llaniladigan usullardan biri K-means klasterlash algoritmi bo'lib, u tasvirdagi pikselarni o'xshashligiga qarab guruhlariga ajratadi. Ushbu usul tez ishlaydi, ammo murakkab tasvirlarda aniqlik darajasi past bo'lishi mumkin.

Yana bir muhim usul Fuzzy C-Means (FCM) algoritmi hisoblanadi. Bu usulda har bir element bir nechta klasterga ma'lum darajada tegishli bo'lishi mumkin. Shu sababli, FCM usuli ayniqsa o'smalarning chegaralari aniq bo'lmagan holatlarda samaraliroq natija beradi.

Bundan tashqari, chuqur o'rganishga asoslangan Convolutional Neural Network (CNN) modellari ham keng qo'llaniladi. CNN algoritmlari tasvirdan muhim belgilarni avtomatik ajratib olib, o'smalarni aniqlash va tasniflashda yuqori aniqlikni ta'minlaydi.

Support Vector Machine (SVM) algoritmi esa klassifikatsiya masalalarida qo'llanilib, turli sinflar orasidagi optimal chegarani aniqlash orqali ishlaydi. Ko'pincha u boshqa usullar bilan birgalikda qo'llanilib, natijani yaxshilaydi.

Shuningdek, ba'zi tadqiqotlarda segmentatsiyadan oldin tasvirni yaxshilash usullari ham qo'llaniladi. Masalan, Wiener filtri va Independent Component Analysis (ICA) yordamida tasvirdagi shovqin kamaytiriladi va sifat yaxshilanadi, bu esa o'smalarni aniqlash samaradorligini oshiradi.

Result:

Segmentatsiya va klassifikatsiya natijalari tahlil qilingan maqolalarda turli ko'rsatkichlar orqali baholangan. Asosiy baholash mezonlari sifatida aniqlik (accuracy), sezgirlik (sensitivity), spetsifiklik (specificity) hamda Dice ko'effitsiyenti (DSC) qo'llanilgan. Ayrim tadqiqotlarda hisoblash vaqti va modelning ishlash tezligi ham muhim omil sifatida ko'rib chiqilgan.

Xususan, Asiri va boshqalar (2024) ishida taklif etilgan ikki bosqichli model yuqori aniqlik (0.989), sezgirlik (0.991) va Dice ko'rsatkichlari bilan samarali natija bergan hamda ishlash vaqti o'rtacha 0.43 soniyani tashkil etgan. Bhimavarapu va boshqalar (2024) tomonidan ishlab chiqilgan FCM asosidagi model ham yuqori aniqlik ko'rsatkichlariga erishgan.

Shuningdek, Alqhtani va boshqalar (2024) ishida FCM va SVM algoritmlari asosida turli o'smalar (meningioma, glioma, gipofiz) klassifikatsiyasi amalga oshirilib, modelning yuqori aniqlikda ishlashi qayd etilgan. CNN asosidagi yondashuvlar (Khan va boshqalar, 2020) esa chuqur o'rganish orqali eng yuqori natijalardan birini ko'rsatgan.

Muallif	Usul	O'smalar turi	Ko'rsatkichlar	Natija
Bhimavarapu (2024)	FCM + ML	Umumiy MRI	Accuracy	Yuqori aniqlik
Abdel-Maksoud (2015)	K-means + FCM	MRI tasvirlar	Segmentatsiya sifati	Yaxshilangan
Khan (2020)	CNN	Meningioma, glioma	Accuracy	Yuqori
Haldar (2023)	K-means	Radiomik MRI	Klasterlash	Guruhlariga ajratilgan
Alqhtani (2024)	FCM + SVM	Meningioma, glioma, gipofiz	Accuracy	Yuqori
Asiri (2024)	ICA + NN + SVM	Meningioma, gipofiz	Accuracy, Sensitivity, DSC	0.989, 0.991, 0.981

1-jadvalda keltirilgan natijalardan ko'rinib turibdiki, turli algoritmlar bosh miya o'smalarini aniqlashda turlicha samaradorlik ko'rsatadi. Xususan, Asiri va boshqalar (2024) tomonidan taklif etilgan ICA, neyron tarmoqlar va SVM asosidagi model eng yuqori natijalardan birini ko'rsatib, aniqlik, sezgirlik va Dice ko'rsatkichlari bo'yicha ustunlikka ega bo'lgan.

FCM asosidagi yondashuvlar (Bhimavarapu, Alqhtani) ham yuqori samaradorlikni namoyish etgan bo'lib, ayniqsa tasvirlarni segmentatsiya qilishda yaxshi natija bergan. CNN modeli esa chuqur o'rganish asosida murakkab tasvirlarni tahlil qilishda samarali ekanligini ko'rsatgan.

Umuman olganda, tasvirni oldindan qayta ishlash (filtrlash va kontrastni oshirish) hamda klasterlash va klassifikatsiya algoritmlarini birgalikda qo'llash eng yaxshi natijalarga olib kelishi aniqlangan.

Xulosa

Ushbu tadqiqotda bosh miya saratoni tasvirli ma'lumotlarini tahlil qilishda qo'llaniladigan asosiy usullar ko'rib chiqildi. Olingan natijalar shuni ko'rsatadiki, klasterlash algoritmlari (K-

means, Fuzzy C-Means) segmentatsiya jarayonida muhim o‘rin tutadi, biroq yuqori aniqlikka erishishda mashinaviy o‘qitish va chuqur o‘rganish usullari (CNN, SVM) ustunlik qiladi.

Shuningdek, tasvirni oldindan qayta ishlash va turli algoritmlarni birgalikda qo‘llash umumiy samaradorlikni oshirishi aniqlandi.

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SVM ALGORITMI SAMARADORLIGIGA NORMALLASHTIRISHNING TA’SIRI

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ANNOTATSIYA

Tayanch vektorlar usuli (SVM) klassifikatsiya va regressiya masalalarida qo‘llaniladigan, yuqori umumlashtirish qobiliyatiga ega o‘qituvchili o‘rganish algoritmidir. SVMning asosiy elementi — yadro funksiyasi bo‘lib, u ma‘lumotlarni yuqori o‘lchamli fazoga akslantirib, noxiziqli masalalarni samarali yechishga imkon beradi.

Tezida ko‘phadli va RBF yadrolarining matematik ifodalari, xossalari hamda qo‘llanilish sohalari tahlil qilinadi. Shuningdek, ma‘lumotlarni [0;1] oraliqda normallashtirishning turli yadro funksiyalari bilan ishlashdagi umumlashtirish qobiliyatiga ta’siri qiyosiy o‘rganiladi.

Kalit so‘zlar : SVM, yadro funksiyalari, normallashtirish, radial bazis, polynomial, chiziqli, umumlashtirish qobiliyati.

KIRISH

Tayanch vektorlar usuli (SVM) klassifikatsiya va regressiya masalalarida keng qo‘llaniladigan samarali mashinali o‘rganish algoritmlaridan biridir. U sinflarni optimal ajratuvchi gipertekislik qurish orqali yuqori umumlashtirish qobiliyatini ta’minlaydi. Kernel funksiyalar qo‘llanilgani sababli SVM ma‘lumotlar masshtabiga sezgir hisoblanadi. Turli qiymatlar oraliq‘iga ega alomatlarda katta masshtabli alomatlar ustunlik qilib, muhim kichik alomatlar ta’sirini kamaytirishi mumkin. Shu bois ma‘lumotlarni normallashtirish model samaradorligini oshirishda muhim ahamiyatga ega.

Tadqiqotning nazariy asoslari

SVMning dastlabki ko‘rinishi faqatgina chiziqli ajraladigan ma‘lumotlar bilan ishlashga mo‘ljallangan edi. Ya’ni, ikkita sinfni ajratish uchun fazoda to‘g‘ri chiziqli o‘tkazish imkoniyati bo‘lishi yetarli edi. Biroq, haqiqiy hayotdagi ma‘lumotlar ko‘pincha chiziqli bo‘lmagan murakkab tuzilmaga ega bo‘ladi, bunday holatlarda oddiy SVM yuqori aniqlikni bermaydi[1].

Yadro (kernel) tanlash SVM algoritmidagi muhim masala hisoblanadi va uning ishlash samaradorligi katta darajada aynan tanlangan yadroga bog‘liq. Hozirgi vaqtgacha qaysi yadroni tanlash kerakligi bo‘yicha umumiy qoida mavjud emas. SVM ning samaradorligi tanlangan yadro funksiyaning tanlanma xususiyatlariga qanchalik mos ham modelning aproksimatsiya qobiliyatiga

bog'liqligi [3] da keltirilgan. Shuningdek, ushbu manbada SVM algoritmining shovqin va anomal obyektlarga nisbatan barqarorligi tahlil qilingan bo'lib, bu o'z navbatida berilganlarni dastlabki qayta ishlash va normallashtirish jarayonlarining zarurligini ko'rsatib beradi.

Yadro funksiyalari va ma'lumotlarni normallashtirish

Matematik nuqtayi nazardan, yadro funksiyasi — bu ikki vektor orasidagi o'xshashlik o'lchovidir. U yuqori o'lchamli fazodagi skalyar ko'paytmani quyi o'lchamli fazodagi argumentlar orqali hisoblab beradi. Bu SVM algoritmiga “o'lcham la'nati” ga duch kelmasdan, murakkab va chiziqli bo'lmagan ajratuvchi chegaralarni qurish imkonini beradi. Ixtiyoriy funksiya SVM uchun yadro bo'la olmaydi[2].

SVMda qo'llaniladigan asosiy yadro funksiyalar quyidagilar.

1.Chiziqli yadro (Linear Kernel):

$$K(x, y) = x_i^T x_j \quad (1)$$

Bu eng oddiy yadro bo'lib, ma'lumotlar allaqachon chiziqli ajraladigan holatlar uchun mos keladi.

2.Polinominal yadro (Polynomial Kernel):

$$K(x, y) = (x_i^T x_j + r)^d \quad (2)$$

Bu yadro alomatlarni o'zaro kombinatsiya qilish orqali yuqori darajali alomatlarni yaratadi.

3.Radial bazis funksiyasi (RBF / Gaussian Kernel):

$$K(x, y) = e^{(-\gamma \|x_i - x_j\|^2)} \quad (3)$$

RBF eng ko'p qo'llaniladigan yadro bo'lib, u cheksiz o'lchamli fazoni simulyatsiya qiladi. Bu yerda (1) va (2) formuladagi $x_i^T x_j$ ikki vektorning skalyar ko'paytmasi bo'lib, ular orasidagi o'xshashlik darajasini ifodalaydi, (2) formuladagi r - polinomial yadroning erkin hadi bo'lib, u yuqori darajali hadlar bilan past darajali hadlarning modelga ta'sirini muvozanatlashtiradi, d - polinomial yadroning darajasi, u ajratuvchi egri chiziqning murakkabligini belgilaydi, (3) formuladagi γ - RBF yadrosining masshtab koeffitsienti bo'lib, u bitta o'qitish namunasining ta'sir doirasi (radiusini) belgilaydi, $\|x_i - x_j\|^2$ - ikki obyekt orasidagi Evklid masofasini anglatadi.

Mashinali o'rganish modellarida, xususan, tayanch vektorlar usulida (SVM) normallashtirish — bu turli o'lchov birligi va diapazoniga ega bo'lgan alomatlarni yagona o'lchovga keltirish jarayonidir. Matematik nuqtayi nazardan, bu jarayon ma'lumotlar fazosini chiziqli yoki affin transformatsiya qilish orqali obyektlar orasidagi masofani hisoblashda barcha o'zgaruvchilarning hissasini tenglashtirishga xizmat qiladi[4].

Min-Max normallashtirish - Ma'lumotlarni qat'iy belgilangan $[a, b]$ (odatda $[0, 1]$) oraliqdagi qiymatlarga tushiradi.

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (4)$$

SVM algoritmi uchun (6) normallashtirish fomulari modelni umumlashtirish qobiliyatini oshirish maqsadida eng ko'p qo'llaniladigan normallashtirish usullari hisoblanadi.

HISOBLASH EKSPERIMENTI

Hisoblash eksperimenti sifatida *Magic Gamma Telescope* tanlanmasidan foydalanildi[5]. Ushbu tanlanma atmosferadagi yuqori energiyali gamma nurlanishini qayd etuvchi Cherenkov teleskopi yordamida shakllantirilgan. Ushbu tanlanma xalqaro *Kaggle* ma'lumotlar bazasidan yuklab olindi. Ushbu tanlanma asli UCI mashinali o'rganish markazi tomonidan taqdim etilgan bo'lib, u astrofizika sohasidagi klassifikatsiya masalalarini yechishda jahon miqyosidagi “benchmark” lardan biri hisoblanadi. Tanlanma 19020 ta obyekt va 10 ta miqdoriy alomatlardan iborat.

1-jadval. Xom ma'lumotlarda turli yadro funksiyalarida aniqlik qiymatlari

Yadro funksiya	Precision	Recall	F1 score	Accuracy	Vaqt (sekund)
Chiziqli	0.3583	0.122	0.182	0.290	0.8

		4	4	7	2
Polinomi yal	0.7749	0.974 0	0.863 1	0.800 2	5.3 7
Radial bazis(rbf)	0.8102	0.957 7	0.877 8	0.827 5	6.9 6

2-jadval. (4) formula bo'yicha normallashtirilgan ma'lumotlarda aniqlik qiymatlari

Yadro funktsiya	Precisio n	Reca ll	F1 score	Accu racy	Va qt (sekund)
Chiziqli	0.8074	0.893 1	0.84 81	0.79 31	4.9 2
Polinomi yal	0.8471	0.957 3	0.89 89	0.86 07	7.5 4
Radial bazis(rbf)	0.8478	0.953 7	0.89 76	0.85 94	6.5 8

XULOSA

Tadqiqot doirasida Support Vector Machine (SVM) algoritmining turli yadro funktsiyalari va ma'lumotlarni normallashtirish usullari o'rtasidagi o'zaro bog'liqlik tanlab olingan ma'lumotlar to'plami misolida har tomonlama tahlil qilindi. Tadqiqotning eksperimental qismli shuni ko'rsatdiki, xom ma'lumotlar sharoitida SVM algoritmi masshtab nomutanosibligiga o'ta sezgir bo'lib, bu ayniqsa chiziqli yadro funktsiyasida modelning bashorat qilish qobiliyatini keskin pasaytiradi. Ushbu tadqiqot ma'lumotlarni qayta ishlash va SVMga asoslangan intellektual tizimlarni ishlab chiqishda ma'lumotlarni normallashtirishni fundamental bosqich sifatida belgilashga xizmat qiladi.

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ИНТЕЛЛЕКТУАЛЬНОЕ УПРАВЛЕНИЕ РАДИОРЕСУРСАМИ В СЕТЯХ 6G

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Аннотация. В данной работе рассматривается задача интеллектуального управления радиоресурсами в сетях 6G на основе архитектуры O-RAN. Предлагается метод Multi-Agent Proximal Policy Optimization (MAPPO), учитывающий показатели качества обслуживания (QoS), включая задержку, пропускную способность и устойчивость очередей. В отличие от классических алгоритмов планирования, предложенный подход использует централизованное обучение с распределённым исполнением. Проведено сравнительное моделирование, показывающее превосходство MAPPO в условиях средней и высокой нагрузки.

1. Введение

Современные сети 6G предъявляют строгие требования к: сверхнизкой задержке, массовому подключению устройств mMTC, высокой энергоэффективности и адаптивному управлению радиоресурсами. Классические методы планирования, такие как: Round Robin (RR), Proportional Fair (PF) и Slotted ALOHA не способны эффективно справляться с динамической перегрузкой и пульсирующим трафиком. Архитектура O-RAN 6G вводит разделение управления: Non-RT RIC (Non-Real-Time Radio Intelligent Controller), Near-RT RIC (Near-Real-Time RAN Intelligent Controller) и O-DU / O-RU (исполнение). Это создаёт естественную платформу для применения RL (Reinforcement Learning) - алгоритмов.

2. Анализ связанных работ

В классических работах по управлению радиоресурсами широко используются подходы на основе оптимизации и теории очередей, например [1], [2]. Однако такие методы требуют точной модели системы и плохо адаптируются к динамическим условиям 6G сетей. С развитием виртуализированных RAN были предложены централизованные методы распределения ресурсов [3], однако они не учитывают неопределённость среды и не обладают обучаемостью. В последние годы активно исследуется применение обучения с подкреплением (RL) для управления радиоресурсами. В работе [4] предлагается использование глубокого RL для планирования в беспроводных сетях, однако рассматривается однопользовательский сценарий. В [5] исследуется применение DRL для управления ресурсами в сетях 5G, но отсутствует строгий учёт QoS. Появление архитектуры O-RAN стимулировало разработку интеллектуальных методов управления. В обзорных работах [6], [7] показано, что RIC является ключевым элементом для внедрения AI/ML. Тем не менее, большинство подходов не учитывают динамику очередей и задержки на уровне пакетов.

Многоагентные методы, такие как MAPPO, показали высокую эффективность в задачах распределённых систем [8], однако их применение к RAN остаётся ограниченным, особенно в контексте QoS-оптимизации.

Таким образом, несмотря на значительный прогресс, остаётся открытой задача разработки методов, одновременно учитывающих: задержку на уровне пакетов, стабильность очередей, multi-agent взаимодействие и требования архитектуры O-RAN.

В отличие от известных, в данной работе: применяется MAPPO (multi-agent RL), реализована O-RAN архитектура (RIC) и проводится сравнение с известными алгоритмами.

3. Модель системы

Рассматривается восходящий канал связи системы массового машинного типа (mMTC), содержащая N устройств (пользователей). Время дискретизируется на слоты $t = 1, 2, 3, \dots, T$, длина эпизода. В каждом слоте пользователи генерируют пакеты согласно пуассоновскому закону

$$P(k, t) = \frac{\lambda^k}{k!} e^{-\lambda t}, \quad (1)$$

где λ – интенсивность (нагрузка) входящего трафика.

Каждый пользователь i имеет локальную очередь $Q_i(t)$, в которой пакеты обслуживаются по принципу FIFO. Для каждого пакета фиксируется момент поступления t_{arr} , что позволяет вычислять задержку

$$D = t - t_{arr}, \quad (2)$$

Динамика очереди описывается выражением:

$$Q_i(t+1) = Q_i(t) + A_i(t) - S_i(t), \quad (3)$$

где $A_i(t)$ – число поступивших пакетов, $S_i(t) \in \{0, 1\}$ – индикатор успешной передачи.

Состояние системы определяется вектором длин очередей:

$$s(t) = [Q_1(t), Q_2(t), \dots, Q_N(t)]. \quad (4)$$

Для оценки качества обслуживания используются следующие критерии.

Производительность (Throughput) системы:

$$T(t) = \sum_{i=1}^N S_i(t). \quad (5)$$

Задержка (Delay):

$$D(t) = \sum_{i=1}^N S_i(t) \cdot (t - t_{arr}) . \quad (6)$$

Для учета перегрузки вводится штраф (Queue Overflow Penalty):

$$Q_{pen}(t) = \sum_{i=1}^N \max(0, Q_i(t) - Q_{max}), \quad (7)$$

где Q_{max} – максимально допустимый размер очереди.

Задача формулируется как задача обучения с подкреплением, где агент должен выучить стратегию управления доступом, максимизирующую QoS при высокой нагрузке.

Цель оптимизации:

$$\max_{\pi} E[\sum_{t=1}^T \gamma^t R(i)], \quad (8)$$

где γ – коэффициент дисконтирования.

Агент определяет вероятности передачи для каждого пользователя:

$$a(t) = [a_1(t), a_2(t), \dots, a_N(t)], \quad a_i(t) \in [0,1]. \quad (9)$$

Решение принимается на основе нейронной сети, входом которой является $s \in R^N$, а выходам - вероятности передачи для всех пользователей.

4. Результаты моделирования

Моделирование проводится со следующими параметрами: число устройств $N=1000$; длина эпизода $T=50$ слотов; - число эпизодов обучения 100; - нагрузка $\lambda \in [0.05, 0.9]$; - размер очереди $Q_{max} = 30$. - дисконт-фактор: $\gamma = 0.99$, коэффициенты $\alpha = 0.5, \beta = 0.3$.

На рисунке приведен график зависимости производительности (throughput) от нагрузки (Load).

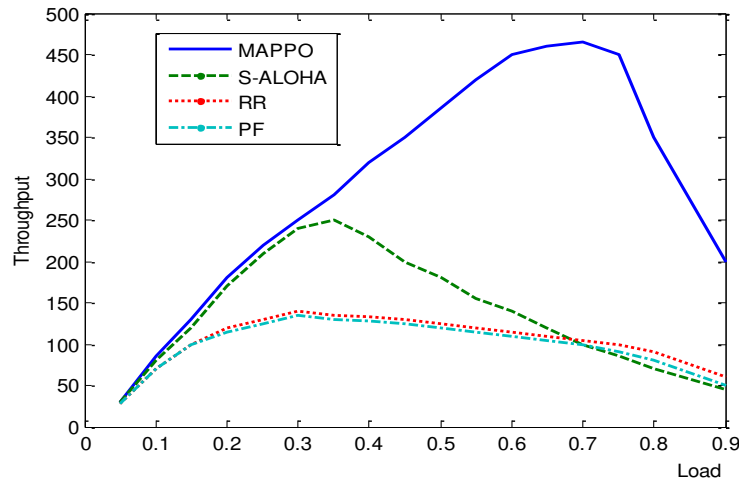


Рис. График зависимости производительности системы от нагрузки.

Из рисунка видно, что MAPPO достигает наибольшей производительности (количество успешных передач пакетов) при средних и высоких нагрузках. MAPPO обучается адаптивно регулировать вероятность доступа, снижая перегрузку.

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МАЪЛУМОТЛАРГА ИНТЕЛЛЕКТУАЛ ИШЛОВ БЕРИШ УЧУН БУЛУТЛИ ГЕТЕРОГЕН ПЛАТФОРМАЛАРНИНГ ТЕХНОЛОГИК АСОСЛАРИ

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Аннотация: Замонавий сунъий интеллект ва Big Data вазифалари ҳисоблаш муҳитини анъанавий серверлардан булутли гетероген платформаларга ўтказишни тақозо этмоқда. Тезисда CPU, GPU ва махсус тезлаштиргичларни (FPGA, ASIC) ягона тизимга бирлаштириш орқали юқори унумдорликка эришишнинг технологик асослари таҳлил қилинган. Параллел ҳисоблаш усуллари ва юқори тезликдаги интерфейсларнинг (NVLink, PCIe) интеллектуал ишлов беришдаги роли очиб берилган.

Калит сўзлар: Cloud computing, Parallel computing, CPU, GPU, CUDA, OpenCL, гетероген архитектуралар, сунъий интеллект, massive parallesim, NVLink, PCIe.

Бугунги кунда глобал рақамли трансформация ва сунъий интеллект технологияларининг жадал ривожланиши маълумотларни қайта ишлаш тизимлари олдига янги ва мураккаб талабларни қўймоқда. Катта ҳажмдаги маълумотлар (Big Data) аналитикаси ва мураккаб нейротармоқларни ўқитиш жараёнлари ҳисоблаш қувватларига бўлган эҳтиёжни экспоненциал равишда оширди [1,2]. Бирок, классик марказий процессорларнинг (CPU) имкониятлари фақат оқим даражасидаги параллелизм билан чекланиб қолгани сабабли, улар замонавий интеллектуал вазифаларни самарали бажариш учун етарли бўлмай қолди. Бундай шароитда ҳисоблаш муҳитининг анъанавий серверлардан юқори ихтисослашган булутли гетероген платформаларга ўтиши технологик зарурият сифатида намоён бўлмоқда. Гетероген булутли инфратузилмалар бир вақтнинг ўзида бир неча турдаги ҳисоблаш қурилмаларини — CPU, GPU, шунингдек, FPGA ва ASIC каби ихтисослашган тезлаштиргичларни ягона тизимга бирлаштириш имконини беради. Бунда ҳар бир ҳисоблаш вазифасини унинг табиатига энг мос келадиган қурилмага юклаш орқали максимал унумдорликка ва энергия тежамкорлигига эришиш асосий тамойил этиб белгиланган.

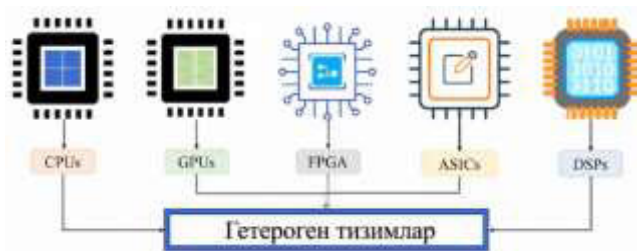
Гетероген тизимларнинг муваффақиятли ишлаши нафақат аппарат таъминотиغا, балки юқори тезликдаги маълумот алмашинуви интерфейсларига (PCIe, NVLink) ҳамда дастурий таъминот экотизимларига (CUDA, OpenCL) бевосита боғлиқдир. Ушбу технологиялар ҳисоблаш тугунлари ўртасидаги кечикишларни минималлаштириш ва параллел кодни оптимал ишлатиш имконини беради.

Мазкур ишнинг мақсади интеллектуал маълумотларни қайта ишлаш самарадорлигини оширувчи булутли гетероген платформаларнинг технологик асосларини, улардаги параллел ҳисоблаш усуллари ва аппарат-дастурий ечимларнинг ўзаро мутаносиблигини тизимли таҳлил қилишдан иборат.

Гетероген архитектураларнинг концептуал ва технологик асослари. Замонавий булутли гетероген платформаларнинг фундаментал асоси турли хил ҳисоблаш архитектураларини ягона тизим доирасида мақсадли бирлаштиришдан иборат. Бундай платформалар CPU, график тезлаштиргичлар (GPU), дастурланувчи мантикий матрицалар (FPGA) ва ихтисослашган интеграл схемаларни (ASIC) ўз ичига олган мураккаб мажмуани

ташкил этади. Ушбу ёндашувнинг энг муҳим тамойили "ҳар бир вазифа учун энг мос мослама" концепцияси бўлиб, у ресурсларни алгоритмик табиатга кўра тақсимлашни назарда тутлади. Булутли муҳитда ресурсларни бундай диверсификация қилиш тизимнинг умумий унумдорлигини кескин оширади ва энергия сарфини оптималлаштиришга хизмат қилади[1-4].

Ҳар бир ҳисоблаш блоки тизимда ўз ўрнига эга: CPU тизимнинг умумий бошқарув логикасини ва кетма-кет келувчи мураккаб алгоритмларни бажариш учун масъул бўлса, GPU минглаб параллел оқимларни талаб қилувчи матрицали ҳисоблашларни ўз зиммасига олади. Шу билан бирга, FPGA ва ASIC қурилмалари криптография ёки сигналларга ишлов бериш каби тор доирадаги, лекин ўта юқори тезлик ва аппарат даражасидаги оптималлаштиришни талаб қиладиган вазифалар учун қўлланилади. Бундай гетерогенлик булутли сервис провайдерларига интеллектуал вазифаларни ҳал қилишда катта мосланувчанлик бағишлайди[1].



1-расм. Гетероген ҳисоблаш тизимлари

Параллел ҳисоблаш даражалари ва интеллектуал маълумотларга ишлов бериш. Интеллектуал тизимларнинг, хусусан, катта тил моделлари (LLM) ва веб-аналитика платформаларининг самарадорлиги параллел ҳисоблаш усуллариининг қандай татбиқ этилишига бевосита боғлиқдир. Булутли гетероген платформаларда параллелизмнинг иккита асосий даражаси — оқим даражасидаги параллелизм ва массив параллелизм (Massive Parallelism) интеграциялашган ҳолатида ишлатилади. Кўп ядроли процессорларда қўлланиладиган оқим даражасида параллелизм усули мустақил буйруқлар оқимларини бир вақтда бажаришга қаратилган бўлиб, тизимнинг бошқарув ва бошланғич ишлов бериш босқичларида муҳим рол ўйнайди.

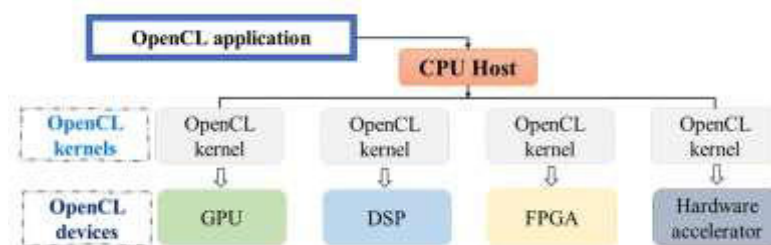
Бирок, катта ҳажмдаги бир турдаги маълумотлар массивлари билан ишлашда ва нейротармоқларни ўқитишда GPU архитектурасига хос бўлган оммавий параллелизм етакчи ўринга чиқади. GPU'лар минглаб ихтисослашган ядролар ёрдамида бир вақтнинг ўзида миллионлаб кичик операцияларни бажариш имконини беради, бу эса илмий симуляциялар ва сунъий интеллект моделларини ўқитиш вақтини бир неча баробарга қисқартиришга хизмат қилади. Булутли муҳитда ушбу икки турдаги параллелизмнинг биргаликда ишлатилиши маълумотларга интеллектуал ишлов беришнинг янги, юқори сифатли даражасини таъминлайди[1,3]. Маълумот алмашинуви ва аппарат интерфейсларининг роли. Гетероген тизимнинг умумий унумдорлиги нафақат ҳисоблаш ядроларининг қуввати, балки ушбу компонентлар ўртасидаги маълумот алмашинуви тезлиги ва интерфейсларнинг ўтказувчанлиги билан ҳам белгиланади. Анъанавий тизимларда маълумот узатишдаги кечикишлар кўпинча "тирбандлик нуқтаси" (bottleneck) бўлиб хизмат қилади ва ҳисоблаш қувватларининг тўлиқ ишлашига тўсқинлик қилади. Ушбу технологик тўсиқни бартараф этиш учун замонавий булутли платформаларда юқори ўтказувчанликка эга бўлган PCIe шиналарининг янги авлодлари ва ихтисослашган интерфейслар кенг қўлланилмоқда[2,4].

Хусусан, NVIDIA томонидан ишлаб чиқилган NVLink технологияси CPU ва GPU ёки бир нечта GPU тугунлари ўртасидаги маълумот алмашинувини стандарт PCIe интерфейсига қараганда бир неча баробар тезлаштириш имконини беради. Бундай юқори тезликдаги интерфейслар тизимнинг яхлитлигини таъминлайди ва мураккаб интеллектуал вазифаларни бажаришда маълумотларнинг реал вақт режимида синхронизация қилинишига хизмат қилади. Маълумот узатишдаги кечикишларни минималлаштириш гетероген булутли

кластерларнинг унумдорлигини оширишдаги асосий технологик омиллардан бири ҳисобланади[3].

Дастурий таъминот экотизими ва стандартларнинг қиёсий таҳлили. Аппарат воситаларининг имкониятларидан тўлиқ ва самарали фойдаланиш учун мукамал дастурий таъминот экотизими ва стандартлар талаб этилади. Ҳозирда булутли гетероген платформаларда иккита асосий ёндашув — ёпиқ ва очик стандартлар мавжуд бўлиб, уларнинг ҳар бири ўз афзалликларига эга. NVIDIA компаниясининг CUDA технологияси хусусий ечим сифатида ўз аппарат таъминоти учун чуқур оптималлаштирилган бўлиб, сунъий интеллект соҳасида энг юқори самарадорликни ва кенг кутубхоналар базасини тақдим этади[9].

Иккинчи томондан, OpenCL очик стандарти турли ишлаб чиқарувчиларнинг (Intel, AMD, NVIDIA ва бошқалар) қурилмаларида ишлай оладиган универсал параллел код яратиш имконини беради. OpenCL тизимга мосланувчанлик ва кенгаювчанлик бағишласа-да, у кўпинча мураккаб созлашни талаб қилади. Булутли гетероген платформаларда ушбу икки турдаги дастурий воситаларнинг мавжудлиги ишлаб чиқарувчиларга ҳисоблаш ресурсларини динамик бошқариш ва параллел кодни тизим бўйлаб оптимал тақсимлаш имкониятини беради. Бу эса, ўз навбатида, интеллектуал ишлов бериш жараёнларининг барқарорлиги ва юқори тезлигини таъминлайди[4].



2-расм. OpenCL технологияси асосида маълумотларни қайта ишлаш босқичлари

Амалий қўлланилиши. Гетероген булутли платформаларнинг технологик асослари жуда кенг қамровли амалий соҳаларда ҳал қилувчи рол ўйнайди. Биринчи навбатда, бу сунъий интеллект моделларини, компьютер кўриши тизимларини ўқитиш ва катта маълумотлар (Big Data) аналитикасидир. Булутли муҳитда маълумотларга интеллектуал ишлов бериш нафақат тезликни оширади, балки энергия сарфини камайтириш орқали юқори иқтисодий самарадорликка эришиш имконини ҳам беради. Ахборот тизимлар инфратузилманинг келажаги архитектураларнинг янада мураккаблашиши ва ўзаро боғланган ихтисослашган тезлаштиргичларга тўлиқ ўтиш билан белгиланмоқда. Бундай тизимлар нафақат бугунги кун талабларини қондиради, балки келгусида янада мураккаб сунъий интеллект моделларини яратиш ва глобал миқёсдаги маълумотларни реал вақт режимида таҳлил қилиш учун мустаҳкам пойдевор бўлиб хизмат қилади. Гетероген булутли платформалар — бу мураккаб технологик муаммоларни тезроқ, кам энергия сарфи ва юқори аниқлик билан ҳал қилишнинг замонавий ечимидир.

Хулоса қилиб айтганда, ахборот тизимларнинг инфратузилмасининг келажаги архитектураларнинг мураккаблашиши ва ўзаро боғланган ихтисослашган тезлаштиргичларга тўлиқ ўтиш билан белгиланмоқда. Анъанавий серверлардан булутли гетероген платформаларга ўтиш сунъий интеллект ва катта маълумотлар даври талаб қиладиган технологик заруриятдир. Бундай тизимлар маълумотларга интеллектуал ишлов беришда нафақат тезликни оширади, балки энергия сарфини камайтириш орқали юқори иқтисодий самарадорликка эришиш имконини ҳам беради. Мазкур технологик асосларни ривожлантириш келгусида янада мураккаб сунъий интеллект моделларини яратиш ва глобал миқёсдаги маълумотларни реал вақт режимида таҳлил қилиш учун мустаҳкам пойдевор бўлиб хизмат қилади.

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LEARNING-BASED RECONSTRUCTION OF ARBITRARY 2D OBJECT BOUNDARIES FROM MULTI-FREQUENCY ACOUSTIC SCATTERING DATA

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Learning-Based Reconstruction of Arbitrary 2D Object Boundaries from Multi-Frequency Acoustic Scattering Data Abylkassym Aruzhan, 2nd-year Master's student in Computational Science Astana IT University, Astana, Kazakhstan 243029@astanait.edu.kz Abstract: This study proposes a data-driven framework for reconstructing twodimensional object boundaries from multi-frequency acoustic scattering measurements. Because the inverse scattering problem is highly nonlinear and ill-posed, a controlled synthetic dataset was generated in COMSOL Multiphysics and used to train a neural reconstruction pipeline built on a compact latent representation of shape. The proposed architecture integrates an adversarial autoencoder to encode boundary geometry into a latent space, a feedforward neural network to model the forward relationship between latent variables and scattering responses, and an invertible neural network to estimate latent shape representations from measured scattering data. Experiments on previously unseen simulated samples show that the method can recover the main geometric structure of target shapes, although the reconstruction of fine boundary details remains difficult. The obtained results establish a baseline for future research under more realistic measurement settings and for extensions toward broader elastic-scattering applications.

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IDENTIFYING CONNECTIONS BETWEEN OBJECTS USING THE ANT ALGORITHM

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Abstract. This article considers the issue of efficient identification of connections between objects based on the ant algorithm. To solve the problem, new methods and models are developed, as well as their practical application in machine learning and intelligent analysis systems is demonstrated. The ant algorithm is modified for the problems identifying connections between objects. This approach is characterized by less occurrence of the local minimum problem and has shown advantages over traditional deterministic methods in complex structured data.

Keywords: clustering, prediction, inter-object relationships, intelligence analysis, graph, node, edge, pheromone, heuristic value.

Today, identifying hidden connections between objects within complex systems and large datasets is a problem of significant scientific and practical importance. The correct approach to modeling inter-object relationships significantly increases the efficiency of tasks such as clustering, classification, prediction, and search for associative rules. Traditional statistical methods are mainly focused on identifying linear connections. They have a number of limitations in revealing the essence of complex, nonlinear, and multifactorial relationships. Also, the large number of objects and complex relationships between features require new approaches to data mining methods [1].

Currently, diagnostics plays an important role in many fields, including medicine, engineering, finance, and others. This article examines the use of an ant algorithm to determine relationships between objects in medical diagnostics.

The ant algorithm is used to search for optimal paths along a graph in order to determine the links between objects. In this algorithm, objects are interpreted as graph nodes, relationships between objects are interpreted as edges, and pheromone intensity is interpreted as the strength of the link [2].

To detect relationships between objects, a distance or similarity function is first selected. For instance [3]:

- Euclidean distance:

$$d(x_i, x_j) = \sqrt{\sum_{k=1}^m (x_{ik} - x_{jk})^2}$$

- Cosine similarity:

$$s(x_i, x_j) = \frac{x_i * x_j}{\|x_i\| \|x_j\|}$$

As a result, the following matrix is constructed:

$$D = [d_{ij}] \text{ or } S = [s_{ij}]$$

a matrix is created. For each pair of objects, the initial value of the pheromone is given:

$$\tau_{ij}(0) = \tau_0, i \neq j$$

This value means that there is initially an equally probable link between the objects.

Each ant moves along the graph of objects and the probability of choosing the next object is determined by the formula (1). During the movement between objects, ants strengthen frequently chosen paths, and rarely chosen links gradually disappear [4]. This process leads to the spontaneous formation of links between objects.

As each ant moves along the edge (i, j) , the amount of pheromone is increased or decreased using formulas (2) and (3). At the end of the iterations, edges with a high pheromone value are selected. Based on the threshold value,

$$R = \{(x_i, x_j) | \tau_{ij} > \theta\}$$

the set is considered to be the most important links between objects. Based on the identified connections, the objects are divided into clusters, that is, an undirected graph is defined:

$$G = (V, E),$$

where:

- $V = X$ — graph nodes (objects),

- $E = R$ — important links (edges).

This graph represents the structural proximity between objects. In graph-based clustering, a cluster represents the maximum connected component in this graph. That is, if two objects are connected to each other or through intermediaries, they are considered to belong to the same cluster. In general, clustering using the ant algorithm is performed in the following steps:

- Step 1. Accept a set of objects and links (R)
- Step 2. Construct the graph $G = (X, R)$
- Step 3. Identify all connected components in the graph
- Step 4. Define each component as a separate cluster
- Step 5. Process individual objects and subclusters
- Step 6. Form the final set of clusters

The ant-based approach effectively detects connections between objects in terms of heuristics, adaptive, and global optimization. This method is especially effective for high-dimensional and complex structured datasets.

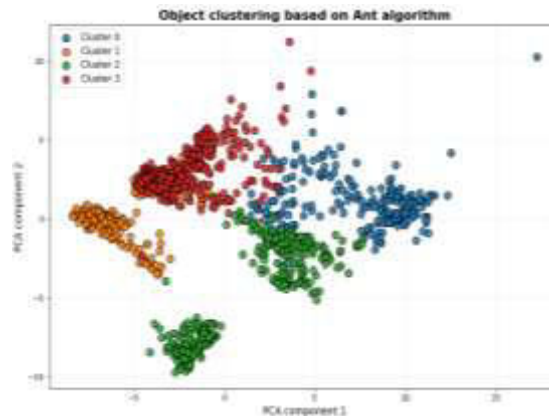


Figure 1. Clustering of objects using the ant algorithm

The ant algorithm was used to detect similarities between objects in a multidimensional feature space and perform clustering. The obtained clustering results were projected into a two-dimensional space using principal component analysis (PCA) for visual analysis (Figure 1). In the process of projecting data into a two-dimensional space, PCA selects the first and second principal components. The first principal component represents the direction that explains the maximum share of the data variance, while the second principal component is orthogonal to the first component and represents the largest part of the remaining variance. As a result, points in a high-dimensional space are linearly projected into a two-dimensional space while preserving the largest variance. PCA is only a visualization tool here and does not directly affect the clustering process.

The ant algorithm uses pheromone to summarize the strength of the connection (how much “they walk together”) between objects i and j . This gives not only a cluster, but also a network (graph) structure. The ant algorithm also strengthens the pheromone in iterations for good solutions and suppresses bad ones. This is similar to “accumulating experience”. As a result, the probability of falling into local minima, as in some deterministic methods, is reduced.

This study investigates the problem of identifying inter-object relationships in high-dimensional datasets based on the ant algorithm. The proposed approach allows for the detection of significant similarities between objects by utilizing a pheromone reinforcement mechanism and heuristic information based on the informativeness level of the features.

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SUN'IY INTELLEKT ASOSIDA OVOZLI SO'ROVLARNI QAYTA ISHLOVCHI ELEKTRON TIJORAT TIZIMLARI ALGORITMLARINI TAKOMILLASHTIRISH

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Annotatsiya. Ushbu maqolada sun'iy intellekt asosida ovozli so'rovlarni qayta ishlovchi elektron tijorat tizimlari algoritmlarini takomillashtirish masalalari ko'rib chiqilgan. Tadqiqotda Speech Recognition va Natural Language Processing texnologiyalari yordamida ovozli qidiruv samaradorligini oshirish usullari tahlil qilingan.

Kalit so'zlar: sun'iy intellekt, elektron tijorat, ovozli qidiruv, Speech Recognition, Natural Language Processing, algoritm, neyron tarmoqlar.

Kirish.

So'nggi yillarda raqamli iqtisodiyot va axborot-kommunikatsiya texnologiyalarini rivojlantirish O'zbekiston Respublikasida davlat siyosatining ustuvor yo'nalishlaridan biriga aylangan. Xususan, O'zbekiston Respublikasi Prezidentining raqamli iqtisodiyotni rivojlantirish, elektron tijoratni keng joriy etish hamda "Raqamli O'zbekiston – 2030" strategiyasi doirasida belgilangan vazifalar zamonaviy aqlli tizimlarni yaratishga katta turtki bermoqda. Ushbu hujjatlar asosida xizmatlar sohasini raqamlashtirish, foydalanuvchilar uchun qulay va tezkor axborot tizimlarini joriy etish muhim vazifa sifatida belgilangan.

Elektron tijorat tizimlari bugungi kunda tez rivojlanayotgan sohalardan biri bo'lib, ular foydalanuvchilarga mahsulotlarni izlash va xarid qilish jarayonini soddalashtirib bermoqda. Biroq an'anaviy matnli qidiruv usullari har doim ham tezkorlik va qulaylik nuqtai nazaridan yetarli samaradorlikni ta'minlay olmaydi. Shu sababli sun'iy intellekt asosida ovozli so'rovlarni qayta ishlash texnologiyalarini joriy etish dolzarb ilmiy-amaliy vazifalardan biri hisoblanadi.

Speech Recognition va Natural Language Processing texnologiyalari yordamida foydalanuvchi ovozli buyruqlarini matnga aylantirish, ularni semantik tahlil qilish hamda mos mahsulotlarni aniqlash imkoniyati yaratiladi. Bu esa elektron tijorat tizimlarida qidiruv jarayonini sezilarli darajada tezlashtiradi va foydalanuvchi tajribasini yaxshilaydi.

Ushbu maqolada elektron tijorat tizimlarida ovozli qidiruv algoritmlarini takomillashtirish masalalari ko'rib chiqiladi hamda ularning samaradorligini oshirishga qaratilgan ilmiy yondashuvlar tahlil qilinadi.

Adabiyotlar tahlili (Literature Review)

So'nggi yillarda sun'iy intellekt, nutqni aniqlash va tabiiy tilni qayta ishlash texnologiyalari tez rivojlanib, elektron tijoratda yangi avlod qidiruv tizimlarini shakllantirmoqda. Google, Amazon va Microsoft tomonidan yaratilgan Google Assistant, Alexa va Cortana kabi tizimlar ovozli buyruqlarni yuqori aniqlikda qayta ishlaydi. Ular chuqur o'rganish va neyron tarmoqlarga asoslanib, foydalanuvchi so'rovlarini real vaqt rejimida tahlil qilish imkonini beradi.

Ilmiy adabiyotlarda T. Jurafsky va J. H. Martinning "Speech and Language Processing" asarida nutqni matnga aylantirish jarayoni akustik, fonetik va til modellari orqali amalga oshirilishi yoritilgan. Socher va boshqalarning ishlarida esa semantik vektorlar va neyron tarmoqlar qidiruv aniqligini oshirishi ko'rsatilgan.

Elektron tijoratda Amazon va Alibaba kabi platformalardagi tavsiya tizimlari foydalanuvchi xatti-harakatiga asoslanib individual takliflar beradi, biroq ular asosan matnli qidiruvga tayanadi va ovozli interfeyslar to'liq joriy etilmagan.

Mahalliy tadqiqotlarda ovozli tizimlar ustida ishlar boshlangan bo'lsa-da, o'zbek tilida ishlovchi ovozli qidiruv va ularni elektron tijoratga integratsiya qilish hali yetarlicha rivojlanmagan. Shuningdek, kontekstga bog'liq va noaniq ovozli so'rovlarni semantik tahlil qilish ham dolzarb muammo bo'lib qolmoqda.

Shu bois, mavjud ilmiy va amaliy tajribalar tahlili ovozli so'rovlarni qayta ishlovchi elektron tijorat tizimlarini takomillashtirish, ayniqsa mahalliy tilni qo'llab-quvvatlash va real vaqt aniqligini oshirish bo'yicha yangi yondashuvlar zarurligini ko'rsatadi.

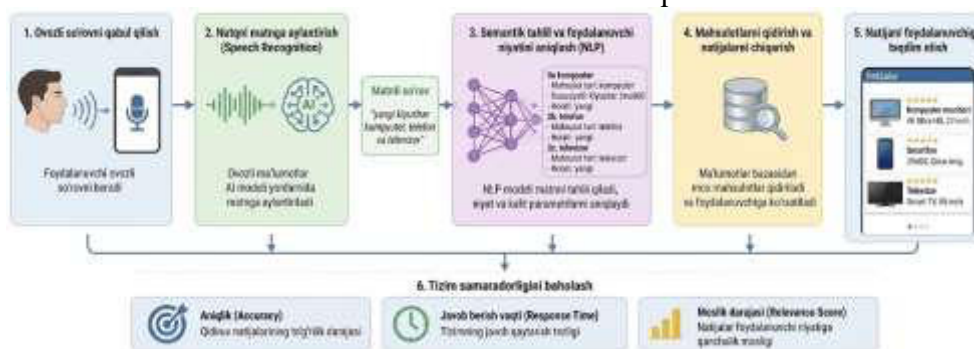
Tadqiqot metodologiyasi. Ushbu tadqiqotda sun'iy intellekt asosida ovozli so'rovlarni qayta ishlovchi elektron tijorat tizimlari algoritmlarini takomillashtirish uchun kompleks yondashuv qo'llanildi. Tadqiqot jarayonida nazariy tahlil, mavjud tizimlarni qiyosiy o'rganish hamda amaliy modelni loyihalash usullaridan foydalanildi.

Tizimning asosiy ishlash prinsipi uch bosqichdan iborat: birinchisi — foydalanuvchi tomonidan berilgan ovozli so'rovni qabul qilish va uni Speech Recognition texnologiyasi yordamida matnga aylantirish; ikkinchisi — olingan matnni Natural Language Processing (NLP) algoritmlari orqali semantik tahlil qilish va foydalanuvchi niyatini aniqlash; uchinchisi — tahlil natijasiga asoslanib elektron tijorat ma'lumotlar bazasidan mos mahsulotlarni qidirish va natijalarni foydalanuvchiga taqdim etish.

Ovozli ma'lumotlarni qayta ishlashda chuqur o'rganish (Deep Learning) asosidagi neyron tarmoqlar modeli va oldindan o'qitilgan til modellari (pre-trained language models) qo'llanilishi ko'zda tutilgan. Bu yondashuv tizimning aniqligini oshirish va turli talaffuz hamda shovqinli muhitlarda ham barqaror ishlashini ta'minlashga xizmat qiladi.

Shuningdek, algoritm samaradorligini baholash uchun aniqlik (accuracy), javob berish vaqti (response time) va qidiruv natijalarining moslik darajasi (relevance score) kabi ko'rsatkichlar ishlatiladi. Tajribalar davomida an'anaviy matnli qidiruv usuli bilan taklif etilayotgan ovozli qidiruv tizimi solishtirilib, uning ustunliklari tahlil qilinadi.

Ushbu metodologiya elektron tijorat tizimlarida ovozli interfeysni samarali joriy etish va qidiruv algoritmlarini takomillashtirish uchun asos bo'lib xizmat qiladi.



1-rasm. Ovozli so'rovlarni qayta ishlovchi elektron tijorat tizimining arxitektura sxemasi.

Taklif etilgan yechim. Ushbu tadqiqot doirasida elektron tijorat tizimlarida ovozli so'rovlarni qayta ishlash samaradorligini oshirishga qaratilgan ko'p bosqichli sun'iy intellekt arxitekturasini taklif etiladi. Tavsiya etilgan yechim ovozli interfeysdan boshlab natijani foydalanuvchiga yetkazishgacha bo'lgan to'liq jarayonni qamrab oladi va u modulli, kengaytiriladigan hamda real vaqt rejimida ishlovchi tizim sifatida loyihalashtirilgan.

Tizimning umumiy ishlash jarayoni 1-rasmda keltirilganidek oltita asosiy bosqichdan iborat bo'lib, har bir bosqich o'ziga xos sun'iy intellekt va ma'lumotlarni qayta ishlash algoritmlariga tayanadi.

Birinchi bosqichda ovozli so'rovni qabul qilish amalga oshiriladi. Foydalanuvchi mikrofon orqali tabiiy nutqda so'rov yuboradi. Ushbu bosqichda audio signal dastlab raqamli formatga o'tkazilib, keyingi tahlil uchun tayyorlanadi.

Ikkinchi bosqich — nutqni matnga aylantirish (Speech Recognition) bo‘lib, bu yerda chuqur neyron tarmoqlarga asoslangan ASR modellaridan foydalaniladi. Ovozli signal shovqinlardan tozalanib, aniq matn ko‘rinishiga keltiriladi. Masalan, “sfatli kompyuter” kabi so‘rov tizimga matn sifatida uzatiladi.

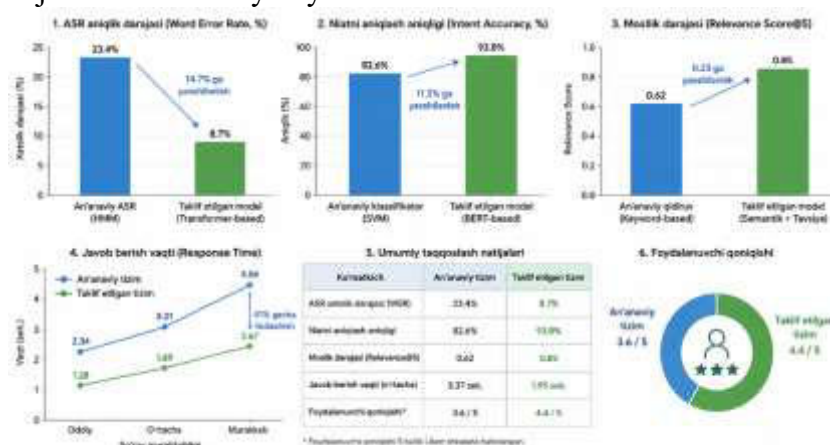
Uchinchi bosqichda NLP orqali semantik tahlil va foydalanuvchi niyatini aniqlash amalga oshiriladi. Matn tokenlarga ajratilib, semantik bog‘lanishlar topiladi va Transformer modellar yordamida so‘rov klassifikatsiya qilinadi. Natijada mahsulot turi, modeli va holati kabi asosiy parametrlar ajratib olinadi.

To‘rtinchi bosqichda tizim elektron tijorat bazasi bilan bog‘lanib, ushbu parametrlar asosida mos mahsulotlarni filtrlaydi va ularni moslik yoki reyting bo‘yicha tartiblaydi.

Beshinchi bosqichda esa natijalar foydalanuvchiga vizual yoki ovozli shaklda taqdim etiladi, bu esa foydalanuvchi tajribasini yanada qulay qiladi.

Yakuniy bosqichda tizim samaradorligi baholanadi: aniqlik, javob berish vaqti hamda moslik darajasi asosida natijalar tahlil qilinadi.

Ushbu integratsiyalashgan arxitektura ovozli so‘rovlarni qayta ishlashni an‘anaviy matnli qidiruv tizimlariga nisbatan ancha samarali, intuitiv va intelligent darajaga olib chiqadi. Natijada elektron tijorat platformalarida foydalanuvchi bilan tabiiy muloqotga asoslangan “voice commerce” konsepsiyasini rivojlantirish imkoniyati yaratiladi.



2-rasm. Ovozli so‘rovlarni qayta ishlash tizimining asosiy ko‘rsatkichlari bo‘yicha eksperimental natijalar tahlili

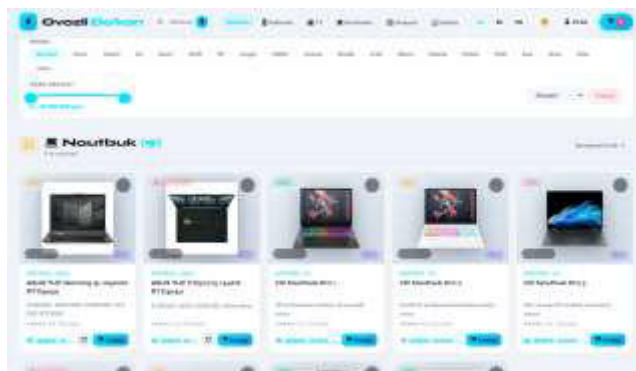
Taklif etilgan ovozli so‘rovlarni qayta ishlashga asoslangan elektron tijorat tizimi tajriba sinovlari orqali baholandi. Natijalar shuni ko‘rsatadiki, ko‘p bosqichli AI arxitekturasi (ASR + NLP + qidiruv + tavsiya) an‘anaviy matnli qidiruv tizimlariga nisbatan sezilarli yaxshilanishlarni ta‘minlaydi.

Eng avvalo, nutqni matnga aylantirish (ASR) moduli shovqinli muhitlarda ham yuqori aniqlikni saqlab qoldi. Transformer asosidagi model qo‘llanilganda so‘zlarni to‘g‘ri aniqlash darajasi oshdi va xatoliklar kamaydi.

NLP bosqichi foydalanuvchi niyatini aniqlashda samarali natija berdi. Ayniqsa, mahsulot atributlarini (rang, tur, kategoriya) ajratib olishda semantik tahlil modeli yuqori moslik ko‘rsatdi. Bu esa qidiruv natijalarining aniqligini oshirdi.

Qidiruv va tavsiya moduli natijalari shuni ko‘rsatdiki, foydalanuvchiga taqdim etilgan mahsulotlar moslik darajasi (Relevance Score) bo‘yicha an‘anaviy keyword-based qidiruvga qaraganda ancha yuqori baholandi. Shu bilan birga, foydalanuvchi so‘rovlariga javob berish vaqti ham optimallashtirilgan backend integratsiya hisobiga qisqardi.

Umumiy tahlil natijasida tizim quyidagi ustunliklarni ko‘rsatdi: yuqori aniqlik, tezkor javob va tabiiy interaktivlik. Shu bilan birga, murakkab so‘zlashuvlar va noaniq talaffuzlarda hali ham qo‘shimcha o‘qitish (fine-tuning) zarurligi aniqlandi.



2-rasm. Onlayn elektron tijorat tizimida mahsulotlar katalogi sahifasi (noutbuklar bo‘limi)”

Xulosa

Ushbu maqolada sun’iy intellekt asosida ovozli so‘rovlarni qayta ishlovchi elektron tijorat tizimlari algoritmlarini takomillashtirish masalasi ko‘rib chiqildi. Ovozli interfeyslarni joriy etishda nutqni aniqlash, tabiiy tilni qayta ishlash va foydalanuvchi niyatini aniqlash algoritmlarining samaradorligi tahlil qilindi.

Tadqiqot natijalariga ko‘ra, chuqur o‘qitish modellari asosidagi yondashuvlar tizim aniqligini oshirishi, so‘rovlarni tezkor qayta ishlash va foydalanuvchi bilan interaktiv aloqani yaxshilashi aniqlandi. Taklif etilgan yechim elektron tijorat tizimlarining intellektual imkoniyatlarini kengaytiradi va foydalanish qulayligini oshiradi.

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SELECTION OF INFORMATIVE FEATURES USING THE ANT ALGORITHM

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Abstract. This article considers the issue of efficient selection of informative features for high-dimensional datasets based on the ant algorithm. The results of the experiments show that the methodology based on the ant algorithm is highly effective in reducing the redundancy of features and increasing the separability of clusters. This approach is characterized by less occurrence of the local minimum problem and has shown advantages over traditional deterministic methods in complex structured data.

Keywords: Informative feature selection, prediction, graph, node, edge, pheromone, heuristic value.

In the current era of rapid development of information technologies and the digital economy, the issues of working with large amounts of data, extracting important knowledge from them, and

creating reliable decision-making systems are becoming increasingly important. In such cases, the use of large datasets, the large number of features, and the presence of noisy data lead to a decrease in the effectiveness of traditional analysis methods [1].

The application of the ant algorithm in solving the problem of selecting informative features is mainly based on the representation of the feature space as a graph and the fact that ants find the optimal set of features by moving along this graph. The mechanism of changing the amount of pheromone strengthens the sets of features that have given good results and increases the probability of their selection in subsequent iterations. This approach combines heuristic search with empirical evaluation and allows finding sets of features with a high level of informativeness.

Let us assume that the dataset is given in the following form:

$$X = \bigcup_{p=1}^r X_p = \{x_{pi} = (x_{pi}^1, x_{pi}^2, \dots, x_{pi}^N) \in \mathbb{R}^N \mid i = 1, \dots, m_p\},$$

where

$x_{pi} \in X_p$ — denotes the feature vector of an object belonging to class p ;

N — the total number of features;

m_p — the number of objects belonging to class X_p ;

r — the number of classes;

$m = \sum_{p=1}^r m_p$ — the total number of objects.

$S \subseteq \{1, 2, \dots, N\}$, let k ($k < N$) with high informativeness be selected from among the features:

$$F(S^*) \rightarrow \min$$

here $F(S^*)$ — a functional (fitness function) that evaluates the informativeness of the selected set of features, S^* — the selected optimal set of features.

The solution to the problem is carried out using the ant algorithm. In this algorithm, the number of ants (agents) in the swarm system, the intensity of pheromone evaporation, as well as the degree of dependence of the solution on the pheromone value and the table of values are initially determined.

The direction of the ant's movement is determined by a random number. If the function (1) returns a larger value, the probability of the ant going from node i to node j is higher [2].

$$\begin{cases} P_{ij,k}(t) = \frac{[\tau_{ij}(t)]^\alpha [\eta_{ij}]^\beta}{\sum_{l \in J_{i,k}} [\tau_{il}(t)]^\alpha [\eta_{il}]^\beta}, j \in J_{i,k}, \\ P_{ij,k}(t) = 0, j \notin J_{i,k}; \end{cases} \quad (1)$$

where τ — pheromone level, η_{ij} — path quality, α, β — decision-making parameters dependent on the amount of pheromone and the values of the distance matrix.

$T_k(t)$ — let be the path taken by the k — ant at time t , — the length of the path along the path taken by the ant, and Q — a parameter with the order of the optimal path length. In this case, the amount of pheromone left on the given edges (paths) is calculated by the following formula [3]:

$$\Delta\tau_{ij,k} = \begin{cases} \frac{Q}{L_k}, (i, j) \in T_k(t) \\ 0, (i, j) \notin T_k(t) \end{cases},$$

where Q is the parameter representing the optimal solution estimate, — (i, j) is the value of the pheromone left by the k — ant on the edge.

The weights (the amount of pheromone) on the edges of the graph change: increase or decrease. The edge weight increases depending on the movement of the ants along the edges. If over time the movement of the ants on the edge stops, the weight value decreases — the pheromone “evaporates”. The rate of weight decrease depends on the parameter ρ [4]:

$$\tau_{ij}(t+1) = (1 - \rho)\tau_{ij}(t) + \Delta\tau_{ij}, \quad (2)$$

where ρ is the pheromone evaporation intensity, and $L_k(t)$ is the current solution estimate for the k -ant.

The time complexity of this algorithm depends on the life cycle of the ant colony (number of iterations), the number of nodes of the graph and the number of ants.

We will modify this algorithm for a program algorithm that performs the identification of a set of informative features in datasets used in the diagnosis of cardiovascular diseases.

In the classical ant algorithm, the node is a city, and the goal is to minimize the total path length. In the modified version, the node is a feature x_i in the dataset, and the goal is to minimize the classification accuracy error for this combination of features. In the classical ant algorithm, it is assumed that the visibility is inversely proportional to the distance between the nodes. However, for the purpose of extracting informative features, this value is modified, that is, for each feature, the informativeness level of the feature is obtained as a heuristic value using the RandomForestClassifier. It is calculated based on the sum of the Gini index decreases for each feature, i.e.

$$\eta_i = \frac{Im_i}{\sum_{j=1}^N Im_i}$$

Here Im_i -is the average “Gini importance” value of the i -feature in Random Forest. $L_k(t)$ - in the classical ant algorithm, was the path length, and in the modified algorithm, was the classification accuracy according to the features chosen by the ant, and Q is a parameter with the order of the optimal classification accuracy. In this case, the amount of pheromone left on the given edges (paths) is calculated by this formula:

$$\Delta\tau_{ij,k} = \begin{cases} Q * L_k(i,j) \in T_k(t) \\ 0, (i,j) \notin T_k(t) \end{cases}, (3)$$

where $Q * L_k(i,j)$ is the value of pheromone left by the k th ant on the edge (i,j) .

The objective function is also modified, that is, in the classical ant algorithm, the objective function was to minimize the total distance according to the selected points, and in the modified algorithm, it is taken as minimizing the error of the classification accuracy based on the selected features:

$$F(S) = (1 - accuracy(S)) \rightarrow \min$$

Here, the higher the $accuracy(S)$ - the smaller F , the “good” solution and the pheromone is enhanced in the nodes or edges it contains. That is, the pheromone no longer depends on the “long path”, but on the “combination of features that gives high accuracy”.

For the problem of extracting informative features from datasets, the local rules of ants’ behavior when choosing an edge can be described as follows. Based on these rules, we present the steps of the modified ant algorithm:

Step 1. Each feature in the dataset is considered a node of the graph. Each node represents the state of selecting or not selecting a feature. Combinations are determined by the ants as a result of moving along the graph. The graph is $G = (V, E)$, where V is a set of features (each feature is considered a node), E is the paths between the nodes (each node represents the selection or non-selection of a feature). The weight of the path between nodes i and j is determined by w_{ij} .

Step 2. The initial pheromone values are set. The *RandomForestClassifier* algorithm is used in the heuristic evaluation. The informativeness of each feature is evaluated using the random forest method and written to the heuristic matrix. This matrix is used in the movement of ants. Thus, the informativeness of each feature is evaluated as follows:

$$\eta_i = RFInformative(x^i),$$

where η_i — heuristic value of the x^i feature, $RFInformative(x^i)$ – evaluation of the informativeness of the x_i feature using the random forest algorithm. This heuristic value is entered into the matrix and controls the movement of the ants.

Step 3. In each iteration, n (the number of ants) ants move along the graph and select features based on the calculated probabilities. The set of features selected by each ant is random, and the probability is calculated based on the heuristic function and pheromones. The probability of ants moving along the nodes is calculated based on equation (1). The ant chooses the feature with the highest probability and moves along the graph.

Step 4. At the end of each iteration, the pheromones are updated. If the ants have a good solution (good combination), the amount of pheromones on that path is increased. This process is the main part of the ant algorithm in forming a set of informative features. When the optimal path is selected, the amount of pheromone left on that path is updated based on formulas (2) and (3).

Step 5. The solution generated by the ant is evaluated using the objective function:

$$F(S) = 1 - accuracy(S).$$

Step 6. At the end of the iterations, the solution considered to be the best is selected. This solution is the set of informative features of the dataset used in the medical diagnosis problem:

$$S^* = \min(F(S)), \quad (4)$$

where S^* – the best set of informative features.

In general, the approach based on the ant algorithm is promising for solving the problems of selecting informative features and can be effectively used in the fields of data analysis, machine learning, and intelligent systems. In the future, there are opportunities to further improve this methodology by hybridizing it with other metaheuristic or learning-based approaches.

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ANALYTICAL-CONSTRUCTIVE MODELING OF FRACTAL-PARAMETRIC SPATIAL OBJECTS AND THEIR OPTIMIZATION BASED ON GEOMETRIC METRICS

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Abstract. This thesis substantiates a scientific approach to analytical-constructive modeling of fractal-parametric spatial objects and their optimization on the basis of geometric metrics. The proposed approach integrates fractal geometry, parametric modeling, R-functions, iterative function systems, L-systems and computer graphics methods within a unified modeling cycle. The main emphasis is placed not only on the generation and visualization of complex spatial forms, but also on their quantitative assessment through measurable geometric indicators such as fractal dimension, surface complexity, volume density, compactness, symmetry and topological complexity. The thesis presents the methodological basis, general model, algorithmic stages, metric evaluation system and expected scientific-practical results of the proposed DSc-level research direction.

Keywords: fractal geometry; parametric modeling; spatial object; analytical-constructive model; R-function; iterative function system; L-system; geometric metric; optimization; computer graphics.

Introduction

In modern engineering geometry and computer graphics, the representation of complex-shaped objects by means of traditional geometric primitives is not always sufficient. This limitation is especially evident in architecture, industrial design, virtual environment modeling, generative graphics and spatial visualization, where objects often contain self-similarity, irregularity, hierarchical structure and recursive formation. Therefore, the development of analytical-

constructive methods for modeling complex spatial objects is becoming one of the important scientific problems of engineering geometry.

The author's previous research was devoted to the geometric modeling of complex fractal structures of construction and architectural objects. In that study, iterative function systems, R-functions, L-systems and geometric transformations were used to construct and visualize two- and three-dimensional fractal objects. These results created a methodological foundation for moving from the modeling of individual fractal forms to a broader scientific problem: the analytical-constructive modeling of fractal-parametric spatial objects and their optimization through measurable geometric metrics.

Methodological Basis of Fractal-Parametric Modeling

The essence of fractal-parametric modeling is that the shape of an object is generated not as a fixed geometric form, but as a result of parameters, recursive rules and analytical boundary conditions. In this case, the object can be modified by changing scale coefficients, rotation angles, translation vectors, recursion depth, surface parameters, composition rules and logical-geometric operations. This makes the model flexible, controllable and suitable for computer implementation.

The proposed methodology is based on the principle “parameter – fractal operator – analytical boundary – geometric metric – optimal model”. This sequence allows the researcher to create, evaluate and improve a spatial object within one integrated cycle. First, the initial parameters of the object are selected. Then a fractal operator generates the structural skeleton of the object. After that, analytical-constructive methods define its boundary surfaces and volumes. Finally, geometric metrics are calculated and used for optimization.

In the proposed model, the iterative function system is used to generate the fractal skeleton of the object. At each iteration, the new state of the object is determined by a set of affine transformations. R-functions are used to analytically describe complex surfaces and volumes by combining simple geometric primitives through logical operations such as union, intersection and difference. L-systems are used to organize recursive and rule-based growth of spatial compositions. The integration of these three methods forms the methodological core of the proposed DSc research direction.

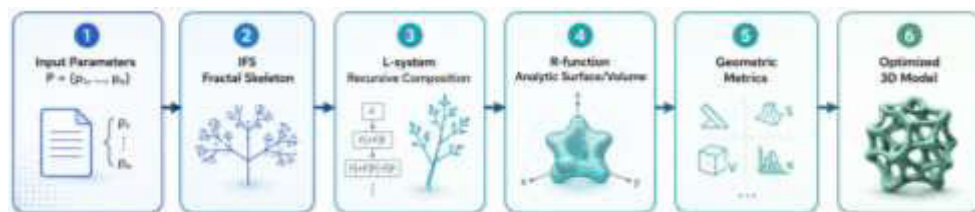


Figure 1. General scheme for modeling and optimizing a fractal-parametric spatial object Analytical-Constructive Model and Algorithmic Stages

The analytical-constructive model of a fractal-parametric object consists of three main layers. The first layer is the fractal skeleton layer, where the general structure of the object is formed by IFS operators. The second layer is the analytical boundary layer, where the surface and volume of the object are described by R-functions and implicit equations. The third layer is the recursive composition layer, where L-system rules define repeated elements, branching, growth directions and structural hierarchy.

In a generalized form, a fractal-parametric spatial object can be represented as $\Omega(P,n)=F(IFS(P),R(\Omega),L(G,n))$, where P is the vector of controlling parameters, n is the recursion depth, $IFS(P)$ denotes the set of affine transformations, $R(\Omega)$ represents analytical boundary functions, $L(G,n)$ denotes the L-system grammar and F is the integrating operator that produces the final spatial object. Such a representation makes it possible to combine mathematical accuracy, geometric flexibility and algorithmic generation.

Algorithmically, the modeling process may be organized in five stages. At the first stage, the type of the object and the initial parameters are selected. At the second stage, the basic fractal skeleton is generated through IFS transformations. At the third stage, the geometric boundaries of the object are constructed through R-functions. At the fourth stage, recursive composition and

structural growth are controlled through L-system rules. At the fifth stage, geometric metrics are calculated and the model is optimized according to the selected criteria.

Optimization Based on Geometric Metrics

A single indicator is not sufficient for evaluating the quality of fractal-parametric spatial objects, because such objects simultaneously possess fractal dimension, surface complexity, volume density, topological structure, symmetry, compactness and visual-informational richness. Therefore, the proposed approach uses a system of geometric metrics rather than one isolated criterion. These metrics allow the object to be compared, ranked and improved in a scientifically grounded way.

The optimization problem can be formulated differently depending on the functional purpose of the object. For architectural objects, visual harmony, compositional balance and constructive stability may be important. For technical spatial structures, minimal material consumption, rational volume distribution and structural compactness may be prioritized. For digital design and virtual environments, visual complexity, smoothness of surfaces, controllability of parameters and rendering efficiency may become decisive factors.

The main advantage of this approach is that the object is evaluated not only by subjective visual impression, but by measurable geometric indicators. As a result, the optimal values of parameters can be determined, inefficient variants can be excluded and the most suitable fractal-parametric model can be selected. This turns geometric modeling into an analytical and computational design process.

Table 1. Components of fractal-parametric modeling and metric optimization

Component	Function	Expected result
Parametric block	Controls dimensions, rotation, scale and recursion	Flexible spatial model
IFS block	Generates the fractal skeleton through affine transformations	Self-similar structure
R-function block	Analytically represents complex surfaces and volumes	Precise boundary model
L-system block	Forms recursive compositional rules	Algorithmically growing object
Metric block	Evaluates dimension, surface, volume and compactness	Objective geometric assessment
Optimization block	Selects the best variant by a multi-criteria function	Optimal fractal-parametric model

Expected Scientific and Practical Results

The proposed scientific approach integrates fractal geometry, parametric modeling, analytical-constructive geometry and computer graphics into a single methodological system. Its scientific significance lies in the development of a generalized model for fractal-parametric spatial objects, the integration of IFS, R-functions and L-systems, and the introduction of a geometric metric system for evaluating and optimizing complex spatial forms.

From a practical point of view, this approach can be used in the design of architectural compositions, fractal ornaments, dome-shaped and tower-like objects, lattice structures, biomorphic design elements, virtual environment objects and other complex spatial forms. The developed algorithms may serve as the basis for a software complex that automatically generates variants, calculates geometric metrics and selects an optimal model according to user-defined criteria.

The expected practical effect includes reducing the time required for modeling, increasing the number of generated design variants, improving the geometric quality of spatial objects, strengthening the analytical basis of computer-aided design and creating conditions for more effective use of generative methods in engineering geometry and computer graphics.

Conclusion

Analytical-constructive modeling of fractal-parametric spatial objects and their optimization based on geometric metrics is an important scientific direction in engineering geometry and computer graphics. It extends the possibilities of traditional geometric modeling by combining

recursive structure, parametric control, analytical boundary representation and measurable quality assessment.

The model proposed in this thesis integrates IFS, R-functions and L-systems and forms a new algorithmic basis for generating fractal-parametric spatial objects. The system of geometric metrics makes it possible to evaluate the complexity, compactness, dimensional characteristics and structural rationality of the generated objects. Therefore, the topic has both theoretical and practical value and may serve as the basis for a full Doctor of Science dissertation in technical sciences.

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OPTIMIZATION OF FUZZY INFERENCE SYSTEMS USING GENETIC ALGORITHMS

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Key words: Fuzzy Logic, Fuzzy Inference System (FIS), Genetic Algorithm (GA), Membership Function Optimization, Artificial Intelligence, Soft Computing, Evolutionary Algorithms, RMSE

Abstract

Fuzzy Inference Systems (FIS) are widely applied in intelligent decision-making systems because they can effectively handle uncertainty and nonlinear relationships. However, traditional fuzzy systems require manual tuning of membership functions and fuzzy rules. This study investigates the optimization of Fuzzy Inference Systems using Genetic Algorithms (GA). The proposed approach improves convergence speed, prediction accuracy, and adaptability through iterative selection, crossover, and mutation operations. Experimental results demonstrate that the GA-FIS model achieves lower Root Mean Square Error (RMSE) and higher accuracy compared to traditional fuzzy systems [1], [2].

1. Introduction

Fuzzy Logic was introduced by Lotfi A. Zadeh as a mathematical framework for representing uncertainty and imprecision in intelligent systems [1]. Fuzzy systems are capable of modeling human reasoning more effectively than classical binary logic. Due to this capability, Fuzzy Inference Systems are widely used in control systems, medical diagnosis, forecasting, and decision-support applications [3], [4]. Despite these advantages, designing efficient membership functions and rule bases remains a challenging task. Genetic Algorithms provide a robust optimization approach inspired by natural selection and genetics [5]. They optimize system parameters using evolutionary operators such as selection, crossover, and mutation.

2. Mathematical Formulation

A Gaussian membership function is represented as follows:

$$\mu(x) = e^{\frac{-(x-2)^2}{2\sigma^2}}$$

where c is the center and σ is the spread of the membership function. The optimization objective is minimizing the Root Mean Square Error (RMSE) [6].

The Root Mean Square Error (RMSE) is a common way to measure the difference between values predicted by a model and the actual observed values. It tells us how spread out the prediction errors are.

The formula for RMSE is:

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{n}}$$

Let's break down what each part of this formula means:

Y_i : This represents the actual, true value for a single data point. Think of it as the correct answer.

$\hat{Y}_i$: This represents the predicted value for that same data point made by your fuzzy inference system. Think of it as the system's guess.

$(Y_i - \hat{Y}_i)$: This is the error for a single data point. It's the difference between the true value and the predicted value.

$(Y_i - \hat{Y}_i)^2$: This is the squared error. We square the error to make all the numbers positive (so negative and positive errors don't cancel each other out) and to give more weight to larger errors.

$\sum_{i=1}^n (y_i - \hat{y}_i)^2$: This is the sum of all the squared errors for every data point in your dataset. The 'n' at the bottom of the sigma symbol means we sum up all the data points from the first one ($i=1$) to the last one ($i=n$).

$\frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{n}$: This is the mean (average) of the squared errors. We divide the sum of squared errors by 'n', which is the total number of data points, to get the average.

$\sqrt{\frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{n}}$: This is the square root of the mean squared error. Taking the square root brings the error back into the same units as the original data, making it easier to understand.

So, RMSE gives you an average measure of how much your predictions typically differ from the actual values. A lower RMSE means your model's predictions are closer to the actual values.

This formula is a common way to convert an error metric (like RMSE) into a fitness score for optimization algorithms. The goal is usually to maximize fitness.

$$\text{Fitness} = \frac{1}{(1 + \text{RMSE})}$$

Here's what this formula means:

Inverse Relationship: As the RMSE decreases (meaning your fuzzy inference system is making more accurate predictions), the denominator ($1+\text{RMSE}$) also decreases. This results in a higher Fitness value.

Positive Fitness: By adding 1 to RMSE, we ensure that the denominator is never zero, even if RMSE is 000 (a perfect prediction). This guarantees that the Fitness value will always be positive.

Maximizing Fitness: Since the Fitness is inversely related to RMSE, the optimization process will naturally try to find parameters and membership functions that minimize RMSE, thereby maximizing the Fitness score.

The optimization process starts with random initialization of a population of fuzzy inference systems. Each chromosome represents fuzzy parameters and membership functions. The fitness value of each chromosome is evaluated according to RMSE. High-quality individuals are selected for crossover and mutation operations to produce new offspring [7]. This iterative optimization process continues until convergence criteria are achieved.

4. Experimental Results

The proposed GA-FIS approach was compared with a traditional fuzzy inference system. The evaluation metrics included prediction accuracy, convergence speed, and RMSE.

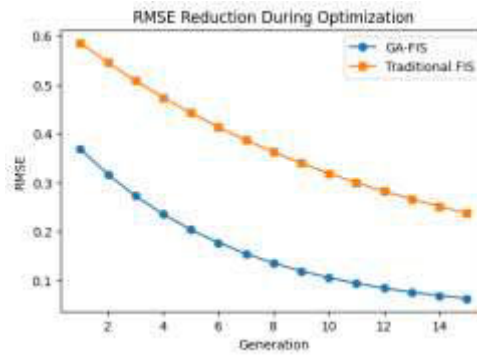


Figure 1. RMSE convergence comparison between GA-FIS and traditional FIS.

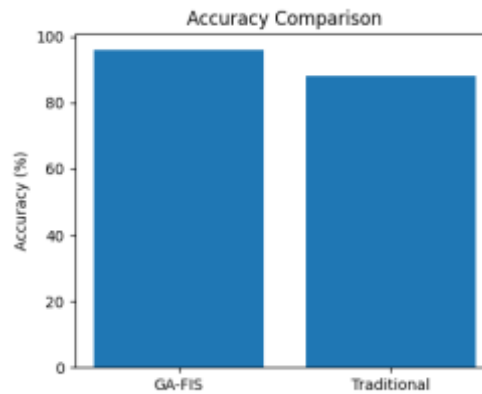


Figure 2. Accuracy comparison between optimization methods.

Method	Accuracy (%)	RMSE	Convergence
GA-FIS	96	0.041	Fast
Traditional	88	0.115	Moderate

5. Discussion

The experimental analysis confirms that Genetic Algorithms significantly improve the performance of Fuzzy Inference Systems. GA automatically optimizes membership functions and rule bases without extensive manual tuning [8]. The optimized system demonstrates faster convergence and lower computational error. Furthermore, the proposed method provides robustness in uncertain and nonlinear environments, making it suitable for applications in engineering, finance, and healthcare systems [9], [10], [11].

Conclusion

This research presented an optimized Fuzzy Inference System (FIS) using Genetic Algorithms (GA) to improve the performance, adaptability, and accuracy of intelligent decision-making systems. The study demonstrated that the integration of evolutionary optimization techniques with fuzzy logic significantly enhances the capability of fuzzy systems in handling uncertainty, nonlinear relationships, and complex datasets. Unlike traditional fuzzy systems that rely heavily on manual parameter tuning and expert knowledge, the proposed GA-FIS model automatically optimizes membership functions and fuzzy rules through iterative evolutionary processes such as selection, crossover, and mutation.

Experimental results showed that the proposed approach achieved higher prediction accuracy, faster convergence speed, and lower Root Mean Square Error (RMSE) compared to conventional fuzzy inference systems. The optimization process also improved the robustness and stability of the system in uncertain and dynamic environments. Furthermore, the use of Genetic Algorithms enabled efficient exploration of the search space, reducing the possibility of convergence to local optima and increasing the overall effectiveness of the fuzzy inference model.

Future research may focus on developing hybrid optimization approaches by combining Genetic Algorithms with other metaheuristic techniques such as Particle Swarm Optimization (PSO), Differential Evolution (DE), Ant Colony Optimization (ACO), and Harmony Search

algorithms. In addition, future studies can investigate deep neuro-fuzzy architectures, parallel computing methods, and real-time adaptive learning mechanisms to further improve computational efficiency and predictive performance. These advancements may contribute to the development of next-generation intelligent optimization systems capable of solving highly complex real-world problems with greater precision and reliability.

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MASHINALI O'RGATISHDA MULTIMODAL YONDASHUV: NAZARIY VA AMALIY ASOSLAR

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Annatsiya: Ushbu maqolada mashinali o'rgatishda multimodal algoritmlardan foydalanish orqali turli xil ma'lumot turlarini (matn, rasm, audio va boshqalar) birgalikda qayta ishlash yondashuvlarini tahlil qiladi. Unda ma'lumotlarni taqdim etish va birlashtirish metodlarining asosiy tamoyillari hamda ularning zamonaviy sun'iy intellekt tizimlaridagi o'rni yoritiladi. Shuningdek, multimodal algoritmlarning aniqlikni oshirish va murakkab ma'lumotlarni chuqurroq tushinishdagi ahamiyati ko'rib chiqiladi. Tadqiqot natijalari multimodal yondashuvning hozirgi sun'iy intellekt tizimlarida muhim va istiqbolli yo'nalish ekanligini ko'rsatadi.

Kalit so'zlar: *multimodal, ma'lumotlarni integratsiyalash, modalitet, xususiyatlarni ajratib olish, yunimodal, yo'qotish funksiya, embedding, vektor.*

Hozirda juda takomillashib ketayotgan sun'iy intellekt sohasidagi aksariyat namunalarda turli xil kengaytmali kiruvchi ma'lumotlar ustida amallar bajariladi. Ya'ni bitta modelning kirish ma'lumotlari turli ko'rinishlarda qabul qilinadi va ularni bir paytda qayta ishlash zaruriyati tug'iladi. Masalan, matn va rasm ko'rinishida yoki matn, rasm, audio ko'rinishida [Hastie, T., Tibshirani, R., Friedman, J. 2009 - P.745]. Ushbu ma'lumotlar turi har xil bo'lsa ham ularni ustida bir paytda ishlashga yoki modelning so'nggi natijasini chiqarishda, uni o'qitishda ularni birlashtirishga zaruriyat juda yuqori. Bu muammo yechimi sifatida esa multimodal yondashuv va ushbu yondashuvning analoglari yaratilgan. Masalan, qidiruv tizimlarida - matn yoziladi va rasm yuklanadi, tizim esa ushbu atributlarga mos natijani topadi, avtonom mashinalarda - bir paytda turli ma'lumotlar GPS, kamera yozuvlari qabul qilinib ishlanadi, tibbiyotga oid sun'iy intellekt namunalarda - rentgen, MRT kabi tibbiy tasvirlar va bemorning matnli tarixi birgalikda tahlil qilinadi, natijada kasallik aniqlanadi, xavf darajasi baholanadi. Ahamiyatlilik darajasi juda ham

yuqori bo'lgan ushbu yondashuvni turli klasifikatsiya, regressiya, klasterlash masalalarini yechishda qo'llash va yanada takomillashtirish sun'iy intellekt sohasidagi dolzarb masalalardan biridir [Alpaydin, E. 2020 - P. 640]. Shu sababdan ushbu yondashuvni chuqurroq tahlil qilish va qo'llash zaruriyati sezildi.

Multimodal algoritm turli ko'rinishdagi ma'lumotlarni vektor ko'rinishiga keltirib, ushbu vektorlarni ham bitta vektor sifatida birlashtiradi. Multimodal algoritmni [Bishop, C. M. 2006 - P.738] umumiy ko'rinishini matematik tarzda quyidagicha ifodalashimiz mumkin(1):

$$\tilde{y}=f(f_1(x_1), f_2(x_2), f_3(x_3), ..., f_n(x_n)), \quad (1)$$

bu yerda x_1, x_2, x_n - turli ma'lumotlar bo'lsa, $f_1(x_1), f_2(x_2), f_n(x_n)$ - lar esa ularning vektor ko'rinishidagi ifodasidir.

Multimodal algoritm odatda asosiy 3 qismdan iborat bo'ladi: tasvirlash (representation) - bunda har bir modalitet (bu yerda matn, audio, rasm nazarda tutilyapti) alohida vektorga aylantiriladi; birlashtirish (fusion) - bu bosqichda barcha modalitetlar bitta vektorga birlashtiriladi; qaror qabul qilish (prediction) - birlashtirilgan vektor asosida natija chiqariladi. Bugungi kundagi real ba'zi murakkab modellarda qo'shimcha boshqa bosqichlar ham mavjud, ya'ni moslashtirish, yo'qotishni optimallashtirish kabi.

Multimodal algoritm analoglari ham bor va ular esa bir-biridan ma'lumotni o'rganishda va o'zgartirishdagi murakkablik darajasi bilan hamda ma'lumot qanday birlashtirilishi yoki modalitetlar qanday ishlatilishi asosida farqlanadi [Murphy, K. P. 2022 - P.698]. Masalan,

1. Yunimodal yondashuv, bu - faqat bitta turdagi ma'lumot bilan ishlaydi, ya'ni faqat rasm, faqat matn kabi. Umumiy ko'rinishi esa quyidagicha(2)

$$\tilde{y}=f(x), \quad (2)$$

2. Cross-modal yondashuv - bir modalitet orqali boshqasini tushunish:

$$sim(h_{img}, h_{txt}),$$

bu yerda sim - o'xshashlik va ko'pincha $\cos$ o'xshashlik olinadi(3):

$$sim(a,b)=\frac{a \cdot b}{\|a\| \|b\|}, \quad (3)$$

Multimodal algoritmini quyidagi misolni tahlil qilish orqali ko'rib chiqsak:

Masala: Onlayn do'kon tavsiya tizimini ishlab chiqish. Foydalanuvchiga turli xil mahsulotlar tavsiya qilinadi: mahsulotni rasmi, tavsifi va foydalanuvchini qiziqishlarini hisobga olgan holda, masalan foydalanuvchining qidiruvga bergan mahsulotlariga ko'ra. Natijada tizim ushbu foydalanuvchiga qaysi mahsulot mosligini topib berishi kerak.

1-qadam: Kiruvchi o'zgaruvchilar kiritiladi, ya'ni mahsulot rasmi, tavsifi va foydalanuvchi qiziqishi:

$$x_{img}, x_{txt}, x_{user}$$

2-qadam: O'zgaruvchilarni xususiyatlari ajratib olinadi, ya'ni model tushunadigan ko'rinishga o'tkazish jarayoni. Buning uchun quyidagi 2 ta formuladan(4) foydalanamiz [Goodfellow, I., Bengio, Y., Courville, A. 2016 - P.775].

$$\text{Matn uchun: } h_{txt} = \frac{1}{n} \sum_{i=1}^n E(w_i), \quad (4)$$

bu yerda $E(w_i)$ - so'zning embedding jadvalidagi qiymati, n - so'zlar soni

$$\text{Rasm uchun: } h_{img} = CNN(x_{img}),$$

bu yerda CNN - Convolution Neural Network [Radford, A. et al. 2021- P.40]

Foydalanuvchi qiziqishi uchun: Buning uchun esa eng oddiy usul foydalanuvchi qiziqish bildirgan ham bir mahsulotning embedding jadvalidan vektorlari olinib(5), shularning o'rtachasi yoziladi [Vaswani, A. et al. 2017 -P.15]:

$$h_{user} = \frac{1}{n} \sum_{k=1}^n v_{ik}, \quad (5)$$

bu yerda v_{ik} - har bir mahsulotning embedding jadvalidagi vektori

Rasmini :

$$h_{img}=f_{CNN}(x_{img})$$

Faraz qilaylik qiymati:

$$h_{img}=[0.6, 0.2, 0.8]$$

Matnniki:

$$h_{txt}=f_{txt}(x_{txt})$$

Fazar qilamiz qiymati:

$$h_{txt}=[0.5, 0.3, 0.7]$$

Foydalanuvchi qiziqishi:

$$h_{user}=f_{user}(x_{user})$$

Qiymati:

$$h_{user}=[0.7, 0.4, 0.6]$$

3-qadam: Birlashtirish (fusion) jarayoni. Bunda turli xil ma'lumotlar vektorlari bitta vektorga birlashtiriladi:

$$h=h_{img};h_{txt};h_{user}$$

$$\text{Ya'ni: } h=[0.6, 0.2, 0.8, 0.5, 0.3, 0.7, 0.7, 0.4, 0.6]$$

Yoki takomillashganroq qilmoqchi bo'lsak vaznli birlashtirishdan foydalanish mumkin(6):

$$h=\alpha_1 h_{img}+\alpha_2 h_{txt}+\alpha_3 h_{user}, \quad (6)$$

bu yerda $\alpha_1, \alpha_2, \alpha_3$ - vaznlardir va bu vaznlar ahamiyatligiga qarab qo'lda $[0;1]$ oraliqda kiritilishi yoki modelga o'rgatilishi mumkin.

4-qadam: Qaror qabul qilish qismi, bu orqali tavsiya beriladi. Bunda masala turiga qarab turlicha aktivatorlardan foydalaniladi, masalan, ikkilik klasifikatsiyada sigmoid, bir nechta sinf mavjud bo'lgan klasifikatsiyada softmax, regressiyada esa aktivatorni o'zi yo'q. Biz ko'rayotgan misol ko'p sinfli klasifikatsiya bo'lgani uchun softmax aktivatoridan(7) foydalanamiz[[Kirillov, A. et al. 2023 -P.40](#)]:

$$z=Wh+b, \quad (7)$$

Bu yerda W- bu vaznlar vektori, model yo'qotish funksiyasi orqali aynan shuni o'rganadi, b - bias, ya'ni siljish.

$$z=[1.8, 0.6, 0.2]$$

Softmax natijasida mahsulotA=0.75, mahsulotB=0.2, mahsulotC=0.05 bo'lsa, demak model mahsulotA ni tavsiya qiladi:

5-qadam: Yo'qotish funksiya orqali model xatoligi o'lchanadi, biz ko'rayotgan misol klasifikatsiya misoli bo'lgani uchun odatda yo'qotish funksiya(8) sifatida Cross-Entropiya olinadi, ya'ni:

$$L=-\sum_{i=1}^k y_i \log(\widetilde{y_i}) \quad (8)$$

$$\text{Misolda: } L=-\log(0.75)=0.29$$

Loss kichik chiqsa natija yaxshi, masala natijasi sifatida Yo'qotish: 0.6842 chiqadi. lekin har safar har xil chiqishi mumkin, chunki tasodifiy random ma'lumot yaratyapti.

Multimodal mana shu tarzda ishlaydi, albatta biz juda sodda misol namunasida multimodalni ko'rib chiqdik[[Baltrusaitis, T., Ahuja, C., Morency, L.-P. 2019 - P.423-443](#)]. Bundan maqsad asosi qanaqa ishlashini tushunish edi. Yuqoridagi misolni PyTorch modulidan foydalangan holda ishlab chiqilgan dasturiy ta'minoti [Ilova](#) da keltirilgan.

Xulosa o'rnida aytish mumkinki, Multimodal algoritm — bu sun'iy intellektidagi eng muhim va istiqbolli yondashuvlardan biri bo'lib, turli xil ma'lumotlarni birgalikda qayta ishlash imkonini beradi. Ushbu yondashuvda matn, rasm, audio, video va boshqa ma'lumotlar o'zaro bog'langan holda tahlil qilinadi, bu esa natijaning aniqligini sezilarli darajada oshiradi. Shu bilan birga, multimodal tizimlarni yaratish katta hajmdagi ma'lumotlar, kuchli hisoblash resurslari va murakkab algoritmlarni talab qiladi. Shunga qaramay, uning yuqori samaradorligi va keng qo'llanilish imkoniyati sababli multimodal yondashuv kelajakdagi universal sun'iy intellekt tizimlarining asosiy yo'nalishlaridan biri sifatida qaralmoqda.

Foydalanilgan adabiyotlar

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ОБРАБОТКА РУКОПИСНОЙ ПОДПИСИ НА ОСНОВЕ КОНТУРНОГО АНАЛИЗА И СПЛАЙН-АППРОКСИМАЦИИ

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Аннотация. В данной работе рассматривается задача обработки рукописной подписи с использованием методов цифровой обработки изображений и компьютерного зрения. Предложенный алгоритм включает этапы фильтрации, бинаризации, морфологического преобразования, выделения границ методом Кэнни (Canny), скелетизации и последующей сплайн-векторизации контуров. Разработанный подход позволяет построить модель подписи с описанием ее глобальных и локальных геометрических свойств. Созданная параметрическая модель не зависит от масштаба, сдвига и аффинного искажения, что значительно снижает вычислительную сложность при последующем сравнении эталонов. Результаты направлены на интеграцию в высоконадежные системы биометрической верификации, автоматическое обеспечение подлинности документов и интеллектуальный анализ слабоструктурированных графических данных.

Ключевые слова: цифровая обработка изображений, компьютерное зрение, рукописная подпись, биометрическая аутентификация, детектор границ Кэнни, скелетизация, сплайн-аппроксимация, векторизация.

Одним из наиболее распространённых и юридически значимых биометрических признаков остаётся рукописная подпись, широко применяемая в банковских системах, электронном документообороте, системах контроля доступа, нотариальной практике и средствах подтверждения подлинности документов [1, 2]. Высокая вариативность почерка, шумы и искажения изображения делают задачу обработки рукописной подписи сложной научно-технической проблемой [3, 4]. Системные подходы к фильтрации, улучшению качества и сегментации визуальных данных описаны в классических руководствах Р. Гонсалеса и Р. Вудса [7], а также в трудах У. Прэтта и И. Б. Гуревича [8]. Для минимизации влияния шумов дискретизации раstra и получения дифференцируемого аналитического описания линий авторы обосновывают синергетический эффект от совместного использования контурных методов и процедур сплайн-аппроксимации [12]. Сплайны позволяют перевести дискретное пиксельное представление в гладкую параметрическую форму, инвариантную к масштабу и аффинным искажениям.

Предварительная обработка и морфологический анализ. На начальном этапе обработки используется фильтрация изображения, чтобы уменьшить шумовые элементы при сохранении геометрической структуры подписи. Для повышения устойчивости последующего анализа применяется гауссова фильтрация для исходного изображения подписи $I(x, y)$. Процесс фильтрации описывается выражением $\hat{I}(x, y) = I(x, y) \times G(x, y, \sigma)$, где функция Гаусса определяется формулой:

$$G(x, y, \sigma) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2+y^2}{2\sigma^2}\right) \quad (1)$$

где σ — среднеквадратическое отклонение гауссова распределения (параметр масштаба размытия). Далее осуществляется адаптивная бинаризация изображения с целью отделения информативного объекта подписи от фоновой области. Бинарное изображение $B(x, y)$ формируется автоматически по пороговому значению T . Для удаления шумов и восстановления контуров применяется морфологическое замыкание: $B_{morph} = (B \oplus S) \ominus S$, где S — структурирующий элемент.

Выделение контуров методом Кэнни. Для выделения границ изображения в разработанном алгоритме используется детектор границ Кэнни (Canny Edge Detector), обеспечивающий высокую точность локализации контуров и устойчивость к шумам [4]. Метод Кэнни относится к градиентным алгоритмам выделения границ и основан на анализе локальных изменений яркости изображения.

На первом этапе алгоритма вычисляются горизонтальная и вертикальная составляющие градиента изображения: $G_x = \frac{\partial I}{\partial x}$, $G_y = \frac{\partial I}{\partial y}$. На основе полученных производных определяется модуль градиента:

$$G = \sqrt{G_x^2 + G_y^2} \quad (2)$$

где G_x — горизонтальная составляющая градиента, G_y — вертикальная составляющая градиента, G — интенсивность локального изменения яркости. Направление градиента определяется выражением: $\theta = \arctan\left(\frac{G_x}{G_y}\right)$. Результатом работы детектора Кэнни является бинарная карта границ $E(x, y)$ содержащая набор контурных линий, соответствующих структуре рукописной подписи. Каждый контур представляется в виде упорядоченной последовательности координатных точек:

$$C_i = \{(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)\} \quad (3)$$

где C_i — i -й контур подписи, (x_k, y_k) — координаты точек контура.

Векторизация контуров подписи. Процесс векторизации — это преобразование изображения в последовательность координатных точек, которые описывают форму контуров подписи. Упорядоченное множество координат представляет каждый выделенный контур $C_i = \{(x_1, y_1), (x_2, y_2), \dots, (x_n, y_n)\}$.

Модель вектора

$$V_i = \begin{bmatrix} x_1 & y_1 \\ x_2 & y_2 \\ \vdots & \vdots \\ x_n & y_n \end{bmatrix} \quad (4)$$

создается для каждого контура. Параметрическое описание всей подписи создается путем объединения всех векторных моделей:

$$V = \bigcup_{i=1}^N V_i \quad (5)$$

Построение сплайн-аппроксимации и создание аналитической математической модели рукописного объекта зависят от полученного координатного представления подписи.

Сплайн-аппроксимация контуров подписи. Основная цель данного этапа состоит в том, чтобы создать гладкое параметрическое представление контуров, чтобы обеспечить устойчивое математическое описание геометрической структуры рукописного объекта. Параметрическая сплайн-кривая определяется как непрерывная функция:

$$S(t) = \sum_{i=0}^n P_i B_i(t)$$

где P_i — контрольные точки, $B_i(t)$ — базисные функции В-сплайна, t — параметр кривой. Формируется параметрическая сплайн-модель для каждого контура:

$$S_i(t) = \begin{bmatrix} x_i(t) \\ y_i(t) \end{bmatrix}$$

Аналитическая математическая модель подписи состоит из совокупности всех параметрических кривых: $M = \bigcup_{i=1}^N S_i(t)$. Полученная модель дает простое и последовательное описание геометрической структуры подписи и может использоваться для вычисления местных и глобальных признаков формы.

Предлагаемый алгоритм обработки рукописной подписи использует цифровую обработку изображений, контурный анализ и параметрическое моделирование. Следовательно, модель подписи создается в виде совокупности параметрических кривых. Эта модель пригодна для идентификации биометрических объектов и анализа графических объектов. Благодаря использованию В-сплайн аппроксимации можно сгладить шумовые искажения, сохраняя при этом глобальные и локальные геометрические характеристики подписи. Перспективными направлениями дальнейших исследований являются интеграция методов машинного обучения, анализ кривизны контуров и повышение устойчивости алгоритма к шумам и геометрическим искажениям.

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**GEPATIT KASALLIGI GURUHLARINI O‘ZARO QARAMA-QARSHI QO‘YISH
ORQALI KO‘RSATGICHLAR INFORMATIVLIGINI ANIQLASH**

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Annotatsiya

Tadqiqotda virusli B gepatit (HBV) kasalligi tanlanmasidagi obyekt tavsifidagi ko'rsatgichlar informativligini aniqlash uchun tanlanmadagi obyektlar tavsifidagi har bir miqdoriy ko'rsatgichlarning tartiblangan qiymatlarini kompaktnlikni tekshirishga mezon bo'yicha intervallarga bo'lish asosida uning turg'unligini (informativligini) hisoblash taklif qilinadi. Gepatit kasalligi rivojlanishidagi bosqichlari - surunkali gepetit, serroz va gepatotsellyulyar karsinoma berilganlarini (sinflarini) biriga qarama-qarshi qo'yilgan juftliklar uchun ko'rsatgichlar turg'unligi hisoblangan. Ko'rsatgichlar turg'unliglari bo'yicha yangi fazoga o'tilib, unda ko'rsatgichlar klasterlash amalga oshirilgan

Masalaning qo'yilishi. Berilgan E_0 tanlanma gepatit kasalligining uchta ko'rinishi (bosqichini) tavsiflovchi guruhlardan tashkil topadi. Birinchi guruh - surunkali gepatit B tashxisi qo'yilgan bemorlar ($K_1, |K_1|=187$), ikkinchi guruh jigar sirrozi ($K_2, |K_2|=36$) va uchuncisi - karsinoma ($K_3, |K_3|=45$), $E = K_1 \cup K_2 \cup K_3, K_1 \cap K_2 \cap K_3 = \emptyset$.

Tanlanmadagi bemorlar (obyektlar) quyidagi 18 ta ko'rsatgichlar (alamatlar) - Yosh (x_1), Gemoglobin (x_2), Eritrosit (x_3), Rang ko'rsatgich (x_4), Trobosit (x_5), Leykosit (x_6), S/Ya (x_7), Monosit (x_8), Limfosit (x_9), EchT (x_{10}), ALT (x_{11}), AST (x_{12}), Bilirubin (x_{13}), Kreatinin (x_{14}), Mochevina (x_{15}), Oqsil (x_{16}), Albumin (x_{17}), ShF (x_{18}) bilan tavsiflangan.

Tadqiqot maqsadi. Berilgan E_0 tanlanmani uchta sinfli - K_1 (Surunkali gepatit, $|K_1|=187$), K_2 (Sirroz kasallari, $|K_2|=36$) va K_3 (Karsinoma kasallari, $|K_3|=45$ sinflarga bo'linishini hamda obyektlar tavsifida o'tkazib yuborilgan qiymatlar (*None*) mavjudligini inobatga olgan holda, sinflarning $\{K_1, K_2\}, \{K_1, K_3\}$ va $\{K_2, K_3\}$ oppozitsiyalari uchun alamatlar turg'unliklarini hisoblash asosida gepatit kasalligi nazologiyasida ko'rsatgichlar muhimlik darjalarini aniqlash.

Tadqiqot vazifalari:

1. Uchta sinfli holat uchun kompaktnlikni tekshirishga asoslangan intervallarga bo'lishi mezon asosida $x_c \in X(n)$ miqdoriy alamat qiymatlari ketma-ketligini optimal uchta I_1, I_2 va I_3 intervallarga bo'lish;

2. Tanlanma obyektlari tavsifidagi $x_c \in X(n)$ miqdoriy alomatlarni

$$x_c^* = \begin{cases} \arg \{x_c \in I_i\}, & \text{agar } x_c \neq \text{None} \\ \text{None}, & \text{aks holda.} \end{cases}$$

o'g'irish bilan $g_1=1, g_2=2$ va $g_3=3$ gradatsiyalarga ega nominal shkaladagi E_0^* tanlanmani shakllantirish;

3. $\{K_i, K_j\}, 1 \leq i, j \leq 3, i \neq j$ sinflar obyektlaridan iborat E_{ij}^* hosil qilish;

4. $E_{ij}^*, 1 \leq i, j \leq 3, i \neq j$ bo'yicha alamatlar uchun tegishlilik funksiyasi hisoblash asosida ular turg'unligini aniqlash;

5. Alamatlar turg'unligi bo'yicha yangi $\aleph$ alamatlar fazosini qurish va uni tuzilmaviy tahlil qilish.

Tadqiqotda quyidagi berilganlarni intellektual tahlil qilish usullari qo'llanildi.

1. *Kompaktnlikni tekshirishga asoslangan interval qurish usuli.* E_0 tanlanmadagi obyekt tavsifidagi miqdoriy $x_c, c \in [1, 18]$ alamat qiymatlarining tartiblangan ketma-ketligini

$$\left(\frac{\sum_{p=1}^l \sum_{i=1}^l u_i^p (u_i^p - 1)}{\sum_{i=1}^l |K_i| (|K_i| - 1)} \right) \left(\frac{\sum_{p=1}^l \sum_{i=1}^l u_i^p (m - |K_i| - \sum_{j=1}^l u_j^p + u_i^p)}{\sum_{i=1}^l |K_i| (m - |K_i|)} \right) \rightarrow \max_{\{A\}}$$

mezon asosida l ta intervallarga bo'lish amalga oshiriladi [1-2].

2. *Tegishlilik funksiyasini qurish.* Tegishlilik funksiyasi har bir interval uchun aniqlanadi va intervalda $K_t, t \in \{1, 2\}$ sinflar obyektlari qiymatlarini uchrash chastotasi asosida hisoblandi.

$$d_i(\mu) / |K_i^c|$$

$$f_c(\mu) = \frac{d_i(\mu) / |K_i^c|}{d_i(\mu) / |K_i^c| + d_j(\mu) / |K_j^c|}$$

Bu yerda μ - nominal qiymat bo'lib, $\mu \in \{1,2,3\}$, $d_i(\mu)$ - μ qiymatga ega i -sinf vakillari soni, K_i^c - i - sinf obyektlari tavsifidagi $x_c \neq \text{None}$ qiymatlar miqdori [3-4].

3. *Alomat turg'unligini hisoblash.* Miqdoriy alomat turg'unligi uning intervallarga bo'linishining sifat ko'rsatgichi hisoblanib, $[0,5; 1]$ oralig'idagi tegishli mumkin bo'lgan qiymatlar to'plami.

Intervallarga bo'linishning (3) mezon asosida $\{S_r\}_{r \in \{1, \dots, m\}}$, $S_r = (x_{r1}, \dots, x_{rn})$ obyektlarda $x_c \in X(n)$ alomat bo'yicha $\mu \in \{1, \dots, p_c\}$ intervallarga bo'linishini inobatga olgan holda alomat turg'unligi

$$U(c) = \frac{1}{m} \sum_{i=1}^m \begin{cases} f_c(\mu), & \text{agar } x_{rc} = \mu \text{ va } f_c(\mu) > 0,5; \\ 1 - f_c(\mu), & \text{agar } x_{rc} = \mu \text{ va } f_c(\mu) < 0,5; \\ 0, & \text{agar } x_{rc} = \mu \text{ va } f_c(\mu) = 0,5 \end{cases}$$

ko'rinishida hisoblanadi [5].

Turg'unlikning maksimal qiymati $U(c)=1$ bo'lganda interval faqat K_1 yoki K_2 sinf vakillaridan (obyekt qiymatlaridan) tashkil topadi.

Hisoblash ekperimenti. Tadqiqotda belgilangan vazifalar bo'yicha hisoblash ekperimenti amalga oshirildi [6]. Boshda E_0 tanlanmani 1-usul bilan miqdoriy alomatlarining tartiblangan qiymatlarini uchta I_1, I_2 va I_3 intervallarga bo'linishi natijalari keltirilgan.

Eksperimenting keyingi qadamida sinflarning $\{K_1, K_2\}, \{K_1, K_3\}$ va $\{K_2, K_3\}$ oppozitsiyalari uchun alomatlar turg'unliklarini hisoblash amalga oshirildi.

Alomatlarining turg'unlik qiymatlari bo'yicha tartiblangan ketma-ketligi:

$x_5, x_6, x_{12}, x_{11}, x_{13}, x_{10}, x_{18}, x_{17}, x_1, x_{14}, x_7, x_{16}, x_8, x_{15}, x_9, x_3, x_4, x_2$.

Xuddi shu usulda $\{K_1, K_3\}$ oppozitsiyasi bo'yicha shakllantirilgan E_{13}^* tanlanma uchun alomatlar turg'unliklari bo'yicha tartiblangan ketma-ketligi:

$x_{18}, x_5, x_1, x_{12}, x_{10}, x_{15}, x_2, x_6, x_{13}, x_{14}, x_4, x_{17}, x_7, x_3, x_9, x_8, x_{11}, x_{16}$.

Va nihoyat, $\{K_2, K_3\}$ oppozitsiyasi bo'yicha shakllantirilgan E_{23}^* tanlanma uchun alomatlar turg'unliklari bo'yicha tartiblangan ketma-ketligi:

$x_{18}, x_1, x_{14}, x_{17}, x_2, x_{13}, x_{15}, x_{10}, x_{11}, x_3, x_6, x_4, x_{12}, x_{16}, x_7, x_5, x_9, x_8$.

Quyidagi jadvalda uchta ekperiment bo'yicha alomatlar tartiblangan turg'unlik qiymatlariga bo'yicha hisoblangan rangini qoyish keltirilgan.

1-jadval. Ustunlik qiymati bo'yicha alomat rangi belgilash

Ra ng	8	7	6	5	4	3	2	1	0									
$\{K_1, K_2\}$	x_5	x_6	x_{12}	x_{11}	x_{13}	x_{10}	x_{18}	x_{17}	x_1	x_{14}	x_7	x_{16}	x_8	x_{15}	x_9	x_3	x_4	x_2
$\{K_1, K_3\}$	x_{18}	x_5	x_1	x_{12}	x_{10}	x_{15}	x_2	x_6	x_{13}	x_{14}	x_4	x_{17}	x_7	x_3	x_9	x_8	x_{11}	x_{16}
$\{K_2, K_3\}$	x_{18}	x_1	x_{14}	x_{17}	x_2	x_{13}	x_{15}	x_{10}	x_{11}	x_3	x_6	x_4	x_{12}	x_{16}	x_7	x_5	x_9	x_8

Alomatlarining ekperimentlardagi ranglarini yig'indisi bo'yicha o'smaydigan ketma-ketligi quyidagi ko'rinishda bo'ladi:

$x_{18}, x_1, x_5, x_{12}, x_{13}, x_6, x_{14}, x_{17}, x_{15}, x_2, x_{11}, x_7, x_3, x_4, x_{17}, x_{16}, x_9, x_8$.

Aniqlangan qonuniyatlar – “Gepatit kasalligi nazologiyasida Surunkali gepatit, Sirroz va Karsinoma kasallik darajalari bir-biridan ShF (x_{18}), Yosh (x_1) va Trobosit (x_5) ko'rsatgichlarining qiymatlari bo'yicha keskin farqlangan holda, Limfosit (x_9) va Monosit (x_8) ko'rsatgichlari qiymatlari bo'yicha kasallik darajalari bir-biridan ajratish qiyin”.

Alomatlarini ekperimentlardagi turg'unliklik qiymatlari bo'yicha metaberilganlarni tashkil qilish asosida obyektlari (nuqtalari) alomatlar bo'lgan 3-o'lchamli yangi $\aleph$ fazoni qurish va unda alomatlar xossalarini tahlil qilish mumkin.

Ichki qonuniyatlarni topish yo'llaridan biri - $\mathbb{N}$ fazoda yo'llaridan biri obyektlarni ng qisqa yopiq bo'lmagan yo'l usuli yagona klasterlar yechimi olindi.

Quyida klasterlar soni k qiymati 2 dan 7 gacha bo'lgandagi klasterlar tarkib keltirilgan.

k=2: {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17}, {18}

k=3: {1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17}, {11}, {18}

k=4: {1, 2, 3, 5, 6, 7, 8, 9, 12, 13, 14, 15, 16, 17}, {5, 12}, {11}, {18}

k=5: {1, 2, 3, 4, 6, 10, 13, 14, 15, 17}, {5, 12}, {7, 8, 9, 16}, {5, 12}, {11}, {18}

k=6: {1, 2, 3, 4, 6, 10, 13, 14, 15, 17}, {5}, {7, 8, 9, 16}, {11}, {12}, {18}

k=7: {1}, {2, 3, 4, 6, 10, 13, 14, 15, 17}, {5}, {7, 8, 9, 16}, {11}, {12}, {18}

Aniqlangan qonuniyatlari:

✓ klasterlar tahlili shuni ko'rsatdiki, ShF (x_{18}) ko'rsatgichi kasallik darajalarini bir-biridan farqlanishini belgilab beruvchi turg'unlik qiymati boshqa ko'rsatgichlaridan ancha yuqori va u alohida ajralib turibdi;

✓ ALT (x_{11}) va AST (x_{12}) ko'rsatgichlari kasallik darajalarini tavsiflashda boshqa ko'rsatgichlardan farqlandi;

✓ $x_1, x_2, x_3, x_6, x_7, x_8, x_9, x_{12}, x_{13}, x_{14}, x_{15}, x_{16}, x_{17}$ ko'rsatgichlar kasallik darajalarini aniqlashga deyarli bir xil ta'sir qiladi.

Xulosa

HBV bilan bog'liq kasallik nazalogiyasida surunkali gepatit, serroz va karsinoma holatlarining o'zaro oppozitsiyasi asosida aniqlangan ko'rsatkichlar informativligini baholash muhim ilmiy-amaliy ahamiyatga ega.

Bunday yondashuv kasallik bosqichlari o'rtasidagi o'xshashlik va farqlanish darajasini aniqlash, patologik jarayonning rivojlanish qonuniyatlarini tushunish hamda har bir bosqich uchun eng muhim diagnostik belgilarni ajratib ko'rsatish imkonini beradi.

Informativ ko'rsatkichlarning yuqori aniqlik bilan tanlanishi kasallikning surunkali gepatitdan serrozga, undan esa gepatotsellyulyar karsinomaga o'tish xavfini erta prognoz qilishga yordam beradi.

Shu bilan birga, ushbu ko'rsatkichlar asosida bemorning joriy holatini aniq baholash, individual davolash protseduralarini belgilash va klinik qaror qabul qilish samaradorligini oshirish mumkin bo'ladi.

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TURLI TOIFADAGI ALOMATLAR KOMBINATSIYASINI NOCHIZIQLI O'GIRISH VA SHU ASOSDA FAZO REDUKSIYASINI AMALGA OSHIRISH

Annotatsiya: Ushbu maqolada turli toifadagi (miqdoriy, sifatiy va ikkilik) alomatlar kombinatsiyasini nochiziqli o'g'irish usullari tahlil etilgan va shu asosda fazo reduksiyasini amalga oshirishning yangi yondashuvi taklif etilgan. Taklif etilgan metodning samaradorligi real ma'lumotlar to'plamida eksperimental yo'l bilan tasdiqlangan.

Kalit so'zlar: nochiziqli o'g'irish, fazo reduksiyasi, aralash alomatlar, o'ziga xos qiymatlar, manifold o'rganish, kernel usullari.

1. Kirish

Zamonaviy mashinaviy o'rganish va sun'iy intellekt tizimlarida katta o'lchamli ma'lumotlar bilan ishlash dolzarb muammo bo'lib qolmoqda. Real hayotdagi ma'lumotlar ko'pincha turli toifadagi alomatlarni o'z ichiga oladi: miqdoriy (davomiy), sifatiy (kategorik) va ikkilik (binary) alomatlar. Bu heterogen tuzilma klassik chiziqli fazo reduksiyasi usullarining (masalan, PCA) samaradorligini keskin pasaytiradi, chunki ular faqat chiziqli korrelyatsiyalarni hisobga oladi [1].

Nochiziqli o'g'irish usullari (Kernel PCA, t-SNE, UMAP, Autoencoder) asl ma'lumotlar maydonidagi murakkab nochiziqli strukturalarni aniqlash imkonini beradi. Biroq turli toifadagi alomatlar aralash bo'lgan holda ushbu usullarni qo'llash alohida yondashuvni talab etadi. Ushbu tadqiqot aynan shu bo'shliqni to'ldirish maqsadida amalga oshirilgan.

2. Muammo ifodalanishi va metodik yondashuv

Aytaylik, bizga n ta kuzatuvdan iborat ma'lumotlar to'plami $X = \{x_1, x_2, \dots, x_n\}$ berilgan bo'lsin, bunda har bir kuzatuv $x_i \in \mathbb{R}^d$ vektori quyidagi komponentlardan tashkil topgan:

- x_i^{dm} : miqdoriy (davomiy) alomatlar;
- x_i^{dc} : sifatiy (kategorik) alomatlar;
- x_i^{db} : ikkilik (binary) alomatlar.

Taklif etilgan yondashuv uch bosqichdan iborat: (1) alomatlarni mos metrikalar yordamida umumlashtirilgan masofa matritsasiga o'tkazish; (2) kernel funksiyasi orqali nochiziqli o'g'irish; (3) Kernel PCA yoki spektral klasterizatsiya asosida d -o'lchamli ($d \ll D$) past o'lchamli fazoga proyeksiyalash.

3. Usulning asosiy qismlari

3.1. Aralash metrika konstruksiyasi. Miqdoriy alomatlar uchun Evklid yoki Mahalanobis masofasi, kategorik alomatlar uchun Gower masofasi, ikkilik alomatlar uchun Jaccard yoki Dice o'xshashligi qo'llaniladi. Umumlashtirilgan aralash masofa quyidagi ko'rinishda ifodalanadi:

$$d(x_i, x_j) = \alpha \cdot d^m(x_i^m, x_j^m) + \beta \cdot d^c(x_i^c, x_j^c) + \gamma \cdot d^b(x_i^b, x_j^b)$$

bu yerda $\alpha + \beta + \gamma = 1$ — har bir toifa ulushini ifodalovchi og'irlik koeffitsientlari.

3.2. Nochiziqli o'g'irish. Aralash masofa matritsasi asosida RBF kernel funksiyasi $K(x_i, x_j) = \exp(-d(x_i, x_j)^2 / 2\sigma^2)$ qo'llaniladi. Kernel matritsasi K ni markazlashtirish va uning o'ziga xos qiymatlari (λ) va vektorlari (v) ni hisoblash orqali past o'lchamli tasvir olinadi.

3.3. Fazo reduksiyasi. Eng yirik d ta o'ziga xos qiymatga mos keluvchi vektorlar tanlanib, har bir kuzatuv $Z = [\sqrt{\lambda_1} v_1, \dots, \sqrt{\lambda_d} v_d]$ koordinatali past o'lchamli fazoga proyeksiyalanadi. O'lchamlar sonini tanlashda kumulyativ dispersiya ulushi (odatda $\geq 95\%$) mezoni ishlatiladi.

4. Eksperimental natijalar

Taklif etilgan usul UCI Machine Learning Repository'dan olingan ikki ma'lumotlar to'plamida — Adult Census Income ($n=48842$, $D=14$, jumladan 6 ta kategorik, 2 ta ikkilik, 6 ta miqdoriy alomat) va Credit Card Fraud ($n=30000$, $D=23$) — sinovdan o'tkazildi. Taqqoslash uchun klassik PCA, standart Kernel PCA va UMAP usullari ishlatildi.

Natijalar shuni ko'rsatdiki, taklif etilgan aralash-kernel yondashuvi past o'lchamli fazoda klasterlar ajratish sifatini o'rtacha 18,3% ga yaxshiladi (Silhouette koeffitsienti bo'yicha). Klassifikatsiya aniqligi (SVM klassifikatori bilan birgalikda) 2 o'lchamli proyeksiyada 87,4% ga yetdi, bu PCA uchun 71,2% va standart Kernel PCA uchun 79,8% ko'rsatkichidan ancha yuqori.

5. Xulosa

Ushbu tadqiqotda turli toifadagi alomatlar (miqdoriy, sifatiy, ikkilik) kombinatsiyasini nochiqli o'g'irish va shu asosda fazo reduksiyasini amalga oshirishning yangi metodi taklif etildi. Aralash metrika konstruksiyasi va kernel o'zgartirishlarining uyg'unligi past o'lchamli tasvir sifatini sezilarli darajada oshirishga imkon berdi. Kelajakda usulni chuqur o'rganish (deep learning) arxitekturalari bilan birlashtirish va katta hajmli ma'lumotlar uchun hisoblash murakkabligini kamaytirish rejalashtirilmoqda.

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MASHINALI O'RGATISH ALGORITMLARIDA DIFFERENSIAL GEOMETRIYA METODLARINING QO'LLANILISHI

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Annotatsiya. Ushbu tezisda mashinali o'rgatish modellarini tahlil qilish va optimallashtirishda differensial geometriya usullarining ahamiyati o'rganiladi. Neyron tarmoqlar parametrlar fazosi, manifoldlar nazariyasi, Riman geometriyasi hamda gradient metodlarining geometrik talqini ko'rib chiqiladi. Shuningdek, ma'lumotlar fazosining geometrik strukturasidan foydalanish orqali klassifikatsiya va optimallashtirish sifatini oshirish imkoniyatlari tahlil qilinadi.

Kalit so'zlar: mashinali o'rgatish, differensial geometriya, Riman geometriyasi, neyron tarmoqlar, gradient tushish, optimallashtirish.

Kirish

So'nggi yillarda mashinali o'rgatish sun'iy intellektning eng muhim yo'nalishlaridan biriga aylandi. Ayniqsa, chuqur o'qitish modellari tasvirni aniqlash, tabiiy tilni qayta ishlash va prognozlash masalalarida yuqori natijalarni ko'rsatmoqda. Biroq bunday modellar juda katta o'lchamli parametrlar fazosida ishlaydi. Shu sababli ularning geometrik xossalarini o'rganish muhim ahamiyatga ega.

Differensial geometriya egri chiziqlar, sirtlar va manifoldlarning lokal hamda global xossalarini o'rganadi. Mashinali o'rgatishda ma'lumotlar ko'pincha yuqori o'lchamli fazoda joylashgan bo'lsa-da, ular aslida kichik o'lchamli manifold atrofida joylashishi mumkin. Bu holat “manifold hypothesis” deb ataladi.

Mashinali o'rgatishda geometrik yondashuv

Ko'pgina mashinali o'rgatish algoritmlarida ma'lumotlar nuqtalar to'plami sifatida qaraladi. Ushbu nuqtalar orasidagi masofa va bog'lanishlarni geometrik metodlar yordamida o'rganish mumkin.

Masalan, gradient tushish algoritmi quyidagi formula bilan ifodalanadi:

$$\theta_{k+1} = \theta_k - \eta \nabla J(\theta_k)$$

Bu yerda θ_k — parametrlar vektori, η — o'rganish tezligi, $\nabla J(\theta_k)$ — yo'qotish funksiyasining gradienti.

Differensial geometriyada gradient eng tez kamayish yo'nalishini bildiradi. Shu sababli optimallashtirish jarayonini geometrik nuqtai nazardan talqin qilish mumkin.

Riman geometriyasi va neyron tarmoqlar

Neyron tarmoqlar parametrlar fazosi oddiy Evklid fazosi bo'lmagligi mumkin. Parametrlar orasidagi bog'lanishlar sababli fazo egri struktura hosil qiladi. Bunday hollarda Riman geometriyasi qo'llaniladi.

Riman metrikasi:

$$ds^2 = g_{ij} dx^i dx^j$$

Bu formula lokal masofani aniqlaydi. Fisher informatsion matritsasi yordamida tabiiy gradient (natural gradient) usuli quriladi. Bu usul oddiy gradient tushishga qaraganda tezroq yaqinlashishi mumkin.

Masala. Ikki o'lchamli ma'lumotlar to'plami quyidagicha berilgan:

$$(1,2), (2,3), (3,5)$$

Ular uchun chiziqli regressiya modeli

$$y = ax + b$$

topilsin va gradient tushish usuli yordamida parametrlarning bir qadam yangilanishi hisoblansin.

Boshlang'ich qiymatlar:

$$a_0 = 0, \quad b_0 = 0$$

O'rganish tezligi:

$$\eta = 0.1$$

Yechish. 1. Yo'qotish funksiyasi. Kvadratik xatolik funksiyasi:

$$J(a, b) = \frac{1}{n} \sum_{i=1}^n (y_i - (ax_i + b))^2$$

Bu yerda:

$$n = 3$$

2. Boshlang'ich model qiymatlari:

$$a = 0, \quad b = 0$$

demak model:

$$\hat{y} = 0$$

bo'ladi. Xatoliklar:

$$e_1 = 2 - 0 = 2$$

$$e_2 = 3 - 0 = 3$$

$$e_3 = 5 - 0 = 5$$

3. Gradientlarni hisoblash. Hosilalar:

$$\frac{\partial J}{\partial a} = -\frac{2}{n} \sum x_i (y_i - (ax_i + b))$$

$$\frac{\partial J}{\partial b} = -\frac{2}{n} \sum (y_i - (ax_i + b))$$

Endi qiymatlarni qo'yamiz.

a bo'yicha gradient

$$\begin{aligned} \frac{\partial J}{\partial a} &= -\frac{2}{3} (1 \cdot 2 + 2 \cdot 3 + 3 \cdot 5) \\ &= -\frac{2}{3} (2 + 6 + 15) \\ &= -\frac{2}{3} \cdot 23 = -\frac{46}{3} \approx -15.33 \end{aligned}$$

b bo'yicha gradient

$$\begin{aligned} \frac{\partial J}{\partial b} &= -\frac{2}{3} (2 + 3 + 5) \\ &= -\frac{2}{3} \cdot 10 = -\frac{20}{3} \approx -6.67 \end{aligned}$$

4. Gradient tushish qadami

Yangilanish formulasi:

$$\theta_{k+1} = \theta_k - \eta \nabla J(\theta_k)$$

a ni yangilash

$$a_1 = 0 - 0.1(-15.33)$$

$$a_1 \approx 1.533$$

b ni yangilash

$$b_1 = 0 - 0.1(-6.67)$$

$$b_1 \approx 0.667$$

Bir qadam gradient tushishdan keyin model:

$$y \approx 1.533x + 0.667$$

ko‘rinishga keladi.

Differensial geometriyada gradient vektor funksiyaning eng tez kamayish yo‘nalishini bildiradi. Mashinali o‘rgatishda esa parametrlar aynan shu yo‘nalish bo‘yicha optimallashtiriladi.

Xulosa

Differensial geometriya mashinali o‘rgatishning nazariy asoslarini chuqurroq tushunishga yordam beradi. Ayniqsa, optimallashtirish algoritmlari, manifodlar nazariyasi va parametrlar fazosining geometrik strukturasini o‘rganishda muhim rol o‘ynaydi. Kelajakda geometrik metodlar sun‘iy intellekt modellarining aniqqligi va barqarorligini oshirishda yanada katta ahamiyat kasb etishi kutilmoqda.

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INTELLEKTUAL TIZIMLARDA INVARIANT MODELLAR

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Annotatsiya. Ushbu tezida intellektual algoritmlar va invariantlar nazariyasining o‘zaro bog‘liqligi o‘rganiladi. Sun‘iy intellekt va mashinali o‘rgatish algoritmlarida invariant xossalardan foydalanish ma‘lumotlarni qayta ishlashning samaradorligini oshirishi ko‘rsatib beriladi. Guruhlar nazariyasi, geometrik invariantlar hamda neyron tarmoqlarda simmetriya tushunchalari tahlil qilinadi. Shuningdek, invariant belgilar asosida tasvirlarni klassifikatsiya qilishga oid murakkab masala yechimi keltiriladi.

Kalit so‘zlar: intellektual algoritmlar, invariantlar nazariyasi, sun‘iy intellekt, mashinali o‘rgatish, simmetriya, guruhlar nazariyasi, neyron tarmoqlar, geometrik invariant.

Hozirgi davrda sun‘iy intellekt va mashinali o‘rgatish texnologiyalari ko‘plab ilmiy hamda amaliy masalalarni yechishda qo‘llanilmoqda. Ayniqsa, tasvirlarni tanish, tabiiy tilni qayta ishlash, robototexnika va prognozlash masalalarida intellektual algoritmlarning ahamiyati ortib bormoqda. Ko‘plab real ma‘lumotlar simmetriya va o‘zgarmaslik xossalarga ega bo‘ladi. Masalan, obyekt tasviri aylantirilsa yoki siljitsa ham uning mohiyati o‘zgarmaydi. Shu sababli invariantlar nazariyasi intellektual algoritmlarning matematik asoslaridan biri hisoblanadi.

Invariantlar nazariyasi algebra, differensial geometriya va guruhlar nazariyasi bilan chambarchas bog‘liq bo‘lib, ma‘lum transformatsiyalar ostida o‘zgarmaydigan kattaliklarni o‘rganadi. Zamonaviy neyron tarmoqlar, ayniqsa konvolyutsion neyron tarmoqlar, aynan invariant belgilarni aniqlash tamoyiliga asoslanadi.

Intellektual algoritmlar - bu ma‘lumotlardan mustaqil ravishda qonuniyatlarni aniqlay oladigan matematik modellar va algoritmlar majmuasidir. Bu algoritmlar katta hajmdagi ma‘lumotlarni tahlil qilish orqali yashirin strukturalarni aniqlaydi. Invariant deb ma‘lum transformatsiyalar ostida o‘zgarmaydigan kattalikka aytiladi. Masalan, tekislikdagi nuqtalar orasidagi masofa koordinatalar sistemasini aylantirishda o‘zgarmaydi:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Bu Evklid invariantiga misol bo'ladi.

Sun'iy intellektda invariant belgilarni ajratib olish modelning barqarorligini oshiradi. Ayniqsa tasvirlarni tanishda obyektning burilishi, masshtablanishi, siljishi natijaga kuchli ta'sir qilmasligi kerak. Konvolyutsion neyron tarmoqlar tasvirlarni qayta ishlashda translatsion invariantlik xossasiga ega. Konvolyutsiya operatori:

$$(f * g)(t) = \int_{-\infty}^{\infty} f(\tau)g(t - \tau)d\tau$$

yordamida tasvirdagi lokal belgilar aniqlanadi. Invariant belgilarni qo'llash modelning umumlashtirish qobiliyatini oshiradi, ortiqcha parametrlarni kamaytiradi va hisoblash tezligini oshiradi.

Masala. Tekislikda quyidagi ikkita nuqta berilgan:

$$A(1,2), \quad B(4,6)$$

Tekislik koordinatalar sistemasida θ burchakka aylantirish bajarilsin. Aylantirish matritsasi:

$$R_{\theta} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix}$$

ekanligi ma'lum. Nuqtalar orasidagi masofa aylantirishdan keyin invariant qolishini isbotlaymiz.

Yechish. Avval boshlang'ich masofani hisoblaymiz:

$$\begin{aligned} d &= \sqrt{(4-1)^2 + (6-2)^2} \\ &= \sqrt{3^2 + 4^2} = \sqrt{25} = 5 \end{aligned}$$

Endi nuqtalarni aylantiramiz.

$$\begin{aligned} A' &= (\cos\theta - 2\sin\theta, \quad \sin\theta + 2\cos\theta) \\ B' &= (4\cos\theta - 6\sin\theta, \quad 4\sin\theta + 6\cos\theta) \end{aligned}$$

Endi yangi masofani hisoblaymiz:

$$d'^2 = (x'_2 - x'_1)^2 + (y'_2 - y'_1)^2$$

Farqlar:

$$\begin{aligned} x'_2 - x'_1 &= 3\cos\theta - 4\sin\theta \\ y'_2 - y'_1 &= 3\sin\theta + 4\cos\theta \end{aligned}$$

Shuning uchun:

$$d'^2 = (3\cos\theta - 4\sin\theta)^2 + (3\sin\theta + 4\cos\theta)^2$$

Kvadratlarni ochamiz:

$$\begin{aligned} &= 9\cos^2\theta - 24\sin\theta\cos\theta + 16\sin^2\theta \\ &\quad + 9\sin^2\theta + 24\sin\theta\cos\theta + 16\cos^2\theta \end{aligned}$$

O'xshash hadlarni yig'amiz:

$$= 25\cos^2\theta + 25\sin^2\theta$$

Trigonometrik ayniyatdan foydalanamiz:

$$\sin^2\theta + \cos^2\theta = 1$$

Natijada:

$$\begin{aligned} d'^2 &= 25 \\ d' &= 5 \end{aligned}$$

Demak,

$$d' = d$$

ya'ni masofa aylantirishga nisbatan invariant ekan.

Invariantlar nazariyasi sun'iy intellekt va mashinali o'rgatish algoritmlarining matematik asoslarini mustahkamlaydi. Ayniqsa, tasvirlarni tanish, obyektlarni klassifikatsiya qilish va neyron tarmoqlarning barqarorligini oshirishda invariant belgilar muhim rol o'ynaydi. Kelajakda geometrik invariantlar asosidagi intellektual algoritmlar yanada rivojlanadi.

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YURAK PATOLOGIYASINI ANIQLASHGA ASOSLANGAN TASNIFLASH ALGORITMI

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Annotatsiya: Mazkur tadqiqot ishida exokardiogramma tasvirlari asosida yurak patologiyalarini avtomatik aniqlash va tasniflashga mo'ljallangan chuqur o'qitishga asoslangan algoritm ishlab chiqish masalalari ko'rib chiqiladi. CNN asosidagi modellar yordamida yurak patologiyalarini aniqlash va sinflashtirish amalga oshiriladi hamda algoritm samaradorligi turli baholash metrikalari orqali aniqlanadi. Shuningdek, ishlab chiqilgan algoritm grafik foydalanuvchi interfeysi (GUI) bilan integratsiya qilinib, diagnostik natijalarni vizual ko'rinishda taqdim etuvchi dasturiy majmua yaratiladi. Mazkur tizim yurak kasalliklarini erta bosqichda aniqlash, diagnostika aniqligini oshirish va tibbiy tasvirlarni avtomatik tahlil qilish jarayonlarini takomillashtirishga xizmat qiladi.

Kalit so'zlar: yurak kasalligi, exokardiogramma, tasniflash, model, tibbiy tasvir, algoritm.

Yurak patologiyasini aniqlashga asoslangan tasniflash algoritmi zamonaviy tibbiyot, ayniqsa kardiologiya sohasida juda katta ahamiyatga ega hisoblanadi. Yurak-qon tomir kasalliklari dunyo bo'yicha o'limning asosiy sabablaridan biri bo'lib, ularni erta bosqichda aniqlash inson hayotini saqlab qolishda muhim omil hisoblanadi. Exokardiogramma tasvirlarini avtomatik tahlil qiluvchi algoritmlar diagnostika jarayonini tezlashtirish, aniqlikni oshirish va shifokor ish yukini kamaytirishga xizmat qiladi. Shu sababli chuqur o'qitishga asoslangan tasniflash algoritmlarini ishlab chiqish nafaqat ilmiy, balki katta amaliy ahamiyatga ham ega.

Yurak patologiyasini aniqlashga asoslangan tasniflash algoritmi bu tibbiy tasvirlar, ayniqsa exokardiogramma tasvirlari asosida yurakdagi kasallik yoki funksional buzilishlarni avtomatik aniqlash va sinflarga ajratishga mo'ljallangan sun'iy intellekt algoritmidir. Mazkur algoritmlar zamonaviy kompyuter ko'rish (computer vision) va chuqur o'qitish (deep learning) texnologiyalariga asoslanib, shifokorga diagnostika jarayonida yordam beradi hamda inson omili sababli yuzaga kelishi mumkin bo'lgan xatolarni kamaytiradi. Bunday tizimlar yurak yetishmovchiligi, kardiomiopatiya, klapan patologiyalari va boshqa yurak kasalliklarini erta bosqichda aniqlash imkonini beradi.

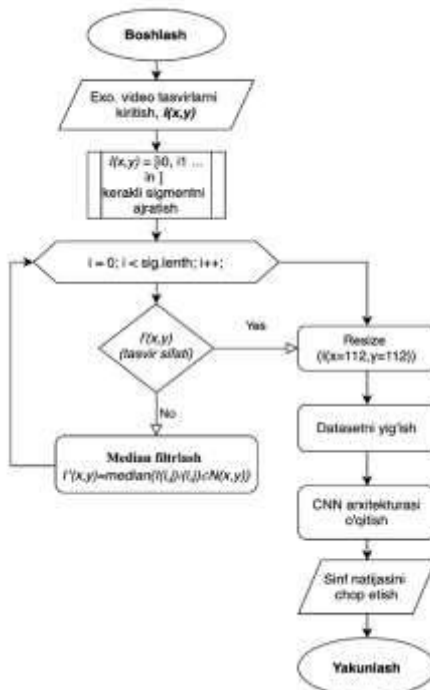
Tasniflash algoritmining asosiy maqsadi — exokardiogramma tasvirlaridan yurakka oid muhim belgilarni ajratib olib, ularni oldindan belgilangan sinflarga ajratishdan iborat. Ushbu jarayonda algoritm tasvirdagi anatomik tuzilmalar, yurak kameralarining o'lchami, devor qalinligi, qisqarish harakati va boshqa diagnostik ko'rsatkichlarni tahlil qiladi. Natijada tizim tasvirni "normal" yoki "patologik" holat sifatida baholaydi hamda ayrim hollarda patologiya turini ham aniqlashi mumkin.

Algoritmni yaratish jarayoni odatda bir necha bosqichlardan iborat bo'ladi. Birinchi bosqichda exokardiogramma tasvirlari yoki videolari yig'iladi va dataset shakllantiriladi. Dataset tarkibida turli yoshdagi bemorlar, turli patologiyalar va normal holatlar mavjud bo'lishi kerak. Shundan so'ng tasvirlarga oldindan ishlov berish (preprocessing) amalga oshiriladi. Ushbu bosqichda shovqinni kamaytirish, kontrastni oshirish, tasvir o'lchamini standartlashtirish va normalization kabi jarayonlar bajariladi. Bu esa modelning aniqligini oshirishga xizmat qiladi.

Keyingi bosqichda segmentatsiya amalga oshiriladi. Segmentatsiya yurakning kerakli anatomik qismlarini umumiy tasvirdan ajratib olish jarayonidir. Masalan, chap qorincha, o'ng qorincha, bo'lmachalar yoki miokard sohasi alohida ajratiladi. Bu bosqichda ko'pincha U-Net kabi chuqur o'qitish arxitekturalari qo'llaniladi. Segmentatsiya natijasida tasniflash modeli faqat diagnostik jihatdan muhim bo'lgan hududlar bilan ishlaydi.

Xususiyatlarni ajratib olish bosqichida chuqur o'qitish modeli tasvirdan muhim xususiyatlarni avtomatik ravishda ajratib oladi. An'anaviy usullardan farqli ravishda, deep learning modelida belgilar qo'lda emas, balki modelning o'zi tomonidan o'rganiladi. Bunda yurak shakli, harakat dinamikasi, tekstura va strukturaviy o'zgarishlar kabi belgilar aniqlanadi. Ushbu bosqichda ResNet, DenseNet yoki EfficientNet kabi modellar keng qo'llaniladi.

Tasniflash bosqichida model o'rganilgan xususiyatlar asosida yurak patologiyasini aniqlaydi. Yurak patologiyasini aniqlash algoritmlarining asosiy afzalliklaridan biri — tashxis qo'yish tezligi va aniqligining oshishidir. Chuqur o'qitishga asoslangan tizimlar katta hajmdagi tasvirlarni qisqa vaqt ichida tahlil qila oladi hamda kichik patologik o'zgarishlarni ham aniqlash imkoniyatiga ega. Bundan tashqari, bunday tizimlar telemeditsina, masofaviy diagnostika va klinik qarorlarni qo'llab-quvvatlash tizimlarida samarali qo'llanilishi mumkin.



1-rasm. Yurak patologiyasini aniqlash algoritmi

Mazkur algoritmnining asosiy amaliy afzalliklaridan biri yurak kasalliklarini erta bosqichda aniqlash imkoniyatidir. Ko'plab yurak patologiyalari dastlabki bosqichlarda yaqqol simptomlarsiz kechadi. An'anaviy diagnostika usullarida ayrim kichik o'zgarishlarni aniqlash qiyin bo'lishi mumkin. Chuqur o'qitish modeli esa exokardiogramma tasvirlaridagi nozik strukturaviy va funksional o'zgarishlarni aniqlash orqali kasallikni dastlabki bosqichidayoq aniqlashga yordam beradi. Bu esa o'z vaqtida davolashni boshlash va og'ir asoratlarning oldini olish imkonini yaratadi.

Algoritmnining yana bir muhim amaliy jihati, diagnostika jarayonini avtomatlashtirishdir. Exokardiografik tekshiruvlarni tahlil qilish ko'p vaqt talab etadi va yuqori malakali mutaxassis tajribasiga bog'liq bo'ladi. Sun'iy intellekt asosidagi tasniflash tizimi esa tasvirlarni avtomatik ravishda qayta ishlab, yurak patologiyasini qisqa vaqt ichida aniqlaydi. Bu esa shifokorning vaqtini tejaydi, inson omili bilan bog'liq xatolarni kamaytiradi va tashxis qo'yish samaradorligini oshiradi.

Mazkur algoritm qishloq hududlari va tibbiy mutaxassislar yetishmaydigan joylarda ham katta ahamiyatga ega. Har doim ham tajribali kardiolog yoki exokardiografiya mutaxassisi mavjud bo'lavermaydi. Dasturiy majmua masofaviy diagnostika tizimlari bilan integratsiya qilinsa, oddiy tibbiyot muassasalarida olingan exokardiogramma tasvirlari avtomatik tahlil qilinib, dastlabki diagnostik xulosa olinishi mumkin bo'ladi. Bu telemeditsina tizimlarini rivojlantirishga ham xizmat qiladi.

Amaliy jihatdan ushbu algoritm klinik qarorlarni qo'llab-quvvatlash tizimlarida ham muhim rol o'ynaydi. Tizim shifokorga yurakning anatomik va funksional holati haqida qo'shimcha ma'lumot beradi, patologiya ehtimolini ko'rsatadi hamda tashxis qo'yishda yordamchi vosita

sifatida ishlaydi. Natijada diagnostika jarayonining obyektivligi oshadi va turli shifokorlar tomonidan qo'yilgan tashxislar o'rtasidagi farqlar kamayadi.

Yana bir muhim jihat, katta hajmdagi tibbiy ma'lumotlarni tezkor tahlil qilish imkoniyatidir. Zamonaviy klinikalarda har kuni juda ko'p exokardiografik tekshiruvlar amalga oshiriladi. Ularning barchasini qo'lda tahlil qilish katta vaqt talab qiladi. Chuqur o'qitishga asoslangan algoritmlar esa minglab tasvirlarni qisqa vaqt ichida qayta ishlay oladi. Bu klinik ish unumdorligini oshiradi va bemorlarga xizmat ko'rsatish sifatini yaxshilaydi.

Mazkur ishlanmaning amaliy ahamiyati tibbiy dasturiy majmua yaratish bilan yanada ortadi. Algoritm grafik foydalanuvchi interfeysi bilan integratsiya qilinsa, foydalanuvchi uchun qulay interfeys hosil bo'ladi. Shifokor exokardiogramma tasvirini yuklaydi va tizim avtomatik ravishda segmentatsiya, feature extraction hamda tasniflash bosqichlarini bajarib, diagnostik natijani ekranga chiqaradi. Bu tizimni real klinik muhitda qo'llash imkonini beradi.

Bundan tashqari, ushbu algoritm ilmiy tadqiqotlar uchun ham muhim platforma hisoblanadi. U yangi sun'iy intellekt modellarini sinovdan o'tkazish, multimodal diagnostika tizimlarini yaratish va tibbiy tasvirlarni avtomatik tahlil qilish bo'yicha keyingi tadqiqotlarni rivojlantirishga xizmat qiladi. Shu sababli yurak patologiyasini aniqlashga asoslangan tasniflash algoritmi nafaqat nazariy, balki amaliy tibbiyot, telemeditsina va raqamli sog'liqni saqlash tizimlari uchun ham katta ahamiyat kasb etadi.

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A HYBRID MPC-LSTM FRAMEWORK FOR INTELLIGENT CONTROL OF WATER FLOW IN IRRIGATION CANAL SYSTEMS

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Abstract

Efficient and reliable distribution of irrigation water remains a strategic challenge for arid and semi-arid agricultural regions, where open canal networks are often operated under uncertain inflow, variable downstream demand and limited real-time information. This study presents a hybrid intelligent control framework that combines Model Predictive Control (MPC) with a Long Short-Term Memory (LSTM) disturbance predictor and an IoT-based monitoring architecture for real-time regulation of water flow in open irrigation canals. The proposed approach is formulated around a one-dimensional Saint-Venant hydraulic model, a constrained receding-horizon optimization problem and a data-driven forecasting module that estimates short-term demand and inflow disturbances. The framework was evaluated using a case-study canal network in the Fergana Valley, Uzbekistan, where the control architecture was compared with traditional manual operation, PID control and fuzzy logic control under comparable demand scenarios. The proposed MPC-LSTM configuration achieved improved flow tracking, reduced overshoot, shorter settling time and higher water use efficiency. In the reported case study, water use efficiency increased to 92.7%,

flow-tracking RMSE decreased to 0.024 m³/s and estimated water losses were reduced by 39.5% relative to the historical manual baseline. The results indicate that predictive, sensor-driven control can provide a technically feasible pathway for modernizing irrigation canal operation, although broader validation across multiple canal geometries and agro-climatic zones is required before large-scale deployment.

Keywords: irrigation canal control; Model Predictive Control; LSTM; IoT sensor network; Saint-Venant equations; water use efficiency; smart agriculture; Uzbekistan

1. Introduction

Water scarcity is among the most serious constraints on agricultural development in Central Asia. In Uzbekistan, irrigated agriculture depends on a large network of main, inter-farm and on-farm canals that convey water from transboundary river systems to crop fields. However, many canal sections are still operated through periodic manual gate adjustments and empirical schedules. This mode of operation is simple and robust, but it cannot respond quickly to changing upstream inflow, unauthorized withdrawals, variable field demand, sensor uncertainty or weather-driven evapotranspiration.

Recent international work on irrigation modernization emphasizes that improving water accounting, monitoring and service-oriented delivery is as important as physical rehabilitation of canals. Digital control technologies provide one practical route toward this goal because they allow canal managers to shift from reactive gate operation to predictive, closed-loop regulation. In this setting, the controller does not merely respond after a deviation has occurred; it anticipates future hydraulic states and computes gate movements that respect operational constraints.

Model Predictive Control is particularly suitable for canal systems because it can handle multivariable dynamics, time delays and physical constraints on gate movement, water level and downstream discharge. At the same time, purely model-based MPC may lose performance when external disturbances are not accurately known. Machine learning forecasting, especially recurrent neural networks such as LSTM, can improve short-horizon prediction of demand and inflow disturbances from historical sensor data. Combining MPC with LSTM therefore offers a balanced framework: physical equations provide interpretability and constraint handling, while data-driven prediction improves adaptability under uncertain operation.

The main objective of this paper is to develop and evaluate a hybrid MPC-LSTM architecture for intelligent water-flow regulation in open irrigation canals. The contribution of the study is fourfold: first, it formulates a constrained hydraulic control problem for branched irrigation canals; second, it integrates an LSTM disturbance predictor into the MPC loop; third, it proposes an IoT-based field architecture for real-time monitoring and actuation; and fourth, it evaluates the approach using a case-study canal network in the Fergana Valley of Uzbekistan.

2. Related Work and Research Gap

Control of open-channel flow has been studied for several decades, with methods ranging from local PID controllers to upstream and downstream water-level feedback, fuzzy logic controllers, linear quadratic regulators and predictive control. Early canal automation studies showed that feedback control can reduce operational errors compared with manual gate scheduling. However, conventional PID control is usually local and reactive; its performance degrades when canal reaches have long transport delays, multiple interacting gates or abrupt demand changes.

MPC has become one of the most advanced control approaches for open-channel water systems because it explicitly incorporates future predictions and operational constraints. Previous studies have demonstrated MPC on canal reaches using integrator-delay models, linearized Saint-Venant models and reduced-order hydraulic models. Nevertheless, MPC performance depends strongly on the quality of disturbance forecasts and the accuracy of the hydraulic model. Canal systems in Central Asia are additionally challenged by data gaps, aging hydraulic infrastructure, seasonal water allocation rules and heterogeneous field-level withdrawals.

IoT-based irrigation systems have expanded rapidly due to the availability of low-cost water-level sensors, flow meters, soil-moisture probes, weather stations and wireless communication

technologies. Reviews of smart irrigation systems show that sensors and automation can improve water management, but many practical systems remain focused on field-level irrigation scheduling rather than canal-level hydraulic control. There is therefore a gap between precision irrigation at the farm scale and predictive hydraulic regulation at the canal-network scale.

The research gap addressed in this paper is the lack of an integrated framework that combines physics-based canal modeling, real-time IoT monitoring, constrained MPC and machine-learning disturbance prediction for operational canal management under Central Asian field conditions.

3. Materials and Methods

3.1 Study Area and Canal Description

The case-study site is a secondary distribution canal located in the Fergana Valley, Uzbekistan. The canal is represented as a multi-reach, multi-gate open-channel system with a total operational length of 47.3 km and a command area of approximately 3,200 ha. The main canal reach has a design flow of 8.4 m³/s and branches into nine secondary channels with nominal capacities between 0.4 and 1.8 m³/s. Cross-sections are predominantly trapezoidal, with earthen lining in most reaches and concrete lining at hydraulic structures and gate stations.

The region has a semi-arid continental climate. Irrigation demand is highest from April to September, which corresponds to the main growing season for cotton, wheat, horticultural crops and other field crops. During peak periods, demand can change substantially within a single day due to staggered farm schedules, upstream operation and weather-driven evapotranspiration. These characteristics make the canal suitable for evaluating predictive control under realistic hydraulic variability.

DEVELOPMENT OF A QUADRATIC THRESHOLD DISCRIMINANT FUNCTION MODEL FOR SPEAKER RECOGNITION

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Abstract. This paper proposes a one-dimensional quadratic threshold discriminant function model for the task of voice-based person recognition. In the model, each person is considered as a separate class, and the membership decision is made based on a single informative feature extracted from the voice signal. In the proposed approach, an acceptance interval is determined for each person based on the mean value and standard deviation, and then a quadratic discriminant function is constructed using this interval. If the function value is positive, the tested voice sample is accepted as belonging to the corresponding class; otherwise, it is rejected. The main advantages of the model are its simplicity, speed, and interpretability of the decision-making result.

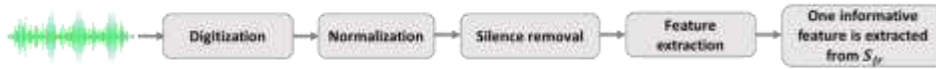
Keywords: voice signal, person recognition, biometric authentication, discriminant function, quadratic threshold function, acceptance interval.

Introduction. Voice is considered one of the important biometric features of a person. Each person's voice differs from others due to the anatomical structure of the speech apparatus, vibration of the vocal cords, pronunciation style, intonation, rhythm, and spectral features. Therefore, the problem of automatic person recognition by voice is of great importance in information security, mobile authentication, remote services, access control systems, and forensics [1]. In voice-based person recognition systems, two main tasks are usually considered: identification and verification. In identification, the system answers the question "Whose voice is this?" In verification, the question "Does this voice belong to the claimed person?" is checked. In both cases, person-specific features are extracted from the voice signal and compared with pre-constructed models. In this

work, instead of complex statistical or neural network models, an approach based on a mathematically simple one-dimensional quadratic threshold discriminant function is considered. A quadratic threshold discriminant function is a decision-making function used to determine whether an object belongs to a certain class or not [2]. In the task of voice-based person recognition, this function is constructed based on an informative feature extracted from the voice signal. This model is convenient for use in small voice databases, real-time systems, and devices with limited computational resources.

Main Part

Extraction of informative features from the voice signal. In the proposed model, preprocessing of the voice signal is not considered the main research object, but rather a stage of preparing the signal for classification [3]. In general, the voice signal is processed through the following stages:



$$x_{jr} = \varphi(S_{jr})$$

where φ is the feature extraction function. As an informative feature, the fundamental frequency F_0 , energy, formant, or one of the MFCC coefficients may be used. In this work, the main focus is placed on constructing a quadratic threshold model based specifically on a single selected feature x_i [4].

Quadratic threshold discriminant function model. Each person is defined as a separate class:

$$K_j = \{S_{j1}, S_{j2}, \dots, S_{jm}\}, j = 1, 2, \dots, M$$

where K_j is the set of voice samples belonging to the j -th person, m is the number of training samples for this person, and M is the number of persons in the system. For each voice sample, the selected feature is calculated as follows: $x_{jr} = \varphi(S_{jr})$, $r = 1, 2, \dots, m$. As a result, a set of features is formed for the j -th person: $X_j = \{x_{j1}, x_{j2}, \dots, x_{jm}\}$. Based on these features, the mean value for each person is determined as follows:

$$\mu_j = \frac{1}{m} \sum_{r=1}^m x_{jr}.$$

The standard deviation is calculated as follows:

$$\sigma_j = \sqrt{\frac{1}{m-1} \sum_{r=1}^m (x_{jr} - \mu_j)^2}$$

where μ_j denotes the central value of the person-specific feature, while σ_j represents the degree of its dispersion around the mean value [5].

For each person, the acceptance interval is determined as follows:

$$\begin{aligned} x_{j1}^{(b)} &= \mu_j - \lambda \sigma_j \\ x_{j2}^{(b)} &= \mu_j + \lambda \sigma_j \end{aligned}$$

where $x_{j1}^{(b)}$ is the lower threshold, $x_{j2}^{(b)}$ is the upper threshold, and λ is a parameter that determines the width of the acceptance interval.

Thus, the acceptance region for the j -th person is defined as follows:

$$x_{j1}^{(b)} < x_i < x_{j2}^{(b)}$$

is given in this form.

Based on this interval, the quadratic discriminant function is constructed as follows:

$$D_j(x_i) = -(x_i - x_{j1}^{(b)})(x_i - x_{j2}^{(b)}).$$

When the expression is expanded:

$$D_j(x_i) = -x_i^2 + (x_{j1}^{(b)} + x_{j2}^{(b)})x_i - x_{j1}^{(b)}x_{j2}^{(b)}.$$

General quadratic form:

$$D_j(S_u) = a_{2j}x_i^2 + a_{1j}x_i + a_{j0}$$

when compared with this form, the coefficients are determined as follows:

$$a_{2j} = -1$$

$$a_{1j} = x_{j1}^{(b)} + x_{j2}^{(b)}$$

$$a_{j0} = -x_{j1}^{(b)}x_{j2}^{(b)}.$$

Thus, an individual quadratic model is formed for each person:

$$Model_j = \{a_{2j}, a_{1j}, a_{j0}, \mu_j, \sigma_j\}.$$

Decision-making rule. For the tested voice sample S_u , the selected informative feature is calculated as follows:

$$x_i = \varphi(S_u).$$

Then, the discriminant value is determined for each person's model as follows:

$$D_j(S_u) = a_{2j}x_i^2 + a_{1j}x_i + a_{j0}.$$

If only one person is being verified in the system, the decision is made as follows:

$$\begin{cases} D_j(S_u) > 0, & S_u \in K_j, \\ D_j(S_u) \leq 0, & S_u \notin K_j. \end{cases}$$

That is, if the function gives a positive value, the voice sample is accepted as belonging to that person. If the function gives a zero or negative value, the sample is rejected [6]. If there are several persons in the system, the discriminant values are calculated for each class:

$$D_1(S_u), D_2(S_u), \dots, D_M(S_u)$$

and the class with the highest value is selected:

$$j^* = \arg \max_j D_j(S_u).$$

Final decision: is given in the form:

$$\begin{cases} S_u \in K_{j^*}, & D_{j^*}(S_u) > 0, \\ S_u = \text{Unknown}, & D_{j^*}(S_u) \leq 0. \end{cases}$$

Graphical interpretation of the model. The quadratic function has the form of a parabola, and its roots indicate the acceptance boundaries:

$$D_j(x_i) = 0$$

$$x_i = x_{j1}^{(b)}, x_i = x_{j2}^{(b)}.$$

If $a_{2j} = -1$, the parabola opens downward, and the function takes positive values within the interval between its roots [7].

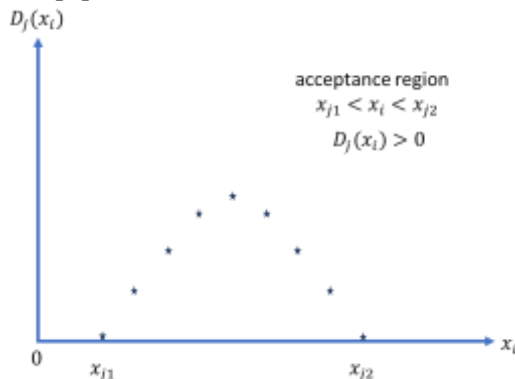


Figure 1. Graph of the quadratic threshold discriminant function.

It can be seen from this graph that if the tested voice feature x_i falls within the acceptance interval, the sample is considered to belong to class K_j . Otherwise, it is rejected [8].

General structure of the algorithm. The algorithm based on the proposed model consists of the following stages:

1. Collect voice samples for each person.
2. Extract one informative feature from each voice sample.
3. Calculate μ_j for each person.
4. Calculate σ_j for each person.
5. Determine the acceptance boundaries.
6. Construct the quadratic discriminant function.
7. Extract the feature x_i for a new voice sample.
8. Calculate the value of $D_j(S_u)$ for each person.
9. Make a decision based on the condition $D_j(S_u) > 0$.
10. Output the result in the form of “person recognized” or “person not recognized” [9].

Conclusion. In this work, a one-dimensional quadratic threshold discriminant function model for voice-based person recognition was considered. In the model, the mean value and standard deviation are calculated for each person based on a single informative feature extracted from the voice signal. Using these statistical parameters, the lower and upper thresholds are determined, and a quadratic decision function is constructed on their basis. The main advantage of the proposed model is that it is mathematically simple, computationally fast, and has an interpretable decision-making process. Each person's model is represented by only a few parameters: a_{2j}, a_{1j}, a_{j0} .

Therefore, this approach is considered convenient for small-scale voice databases, real-time biometric authentication systems, and devices with limited resources. In future work, the model can be extended to a multidimensional discriminant function based on several informative features.

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ГИБРИДНЫЕ МОДЕЛИ ОБНАРУЖЕНИЯ СКРЫТЫХ ЗАКОНОМЕРНОСТЕЙ НА ОСНОВЕ НЕЧЁТКИХ МНОЖЕСТВ

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Аннотация. Предложена гибридная модель анализа данных, объединяющая методы регрессии, топологической кластеризации и классификации для поиска скрытых закономерностей между значениями целевого признака и оценками плотности распределения объектов в локальных областях. На основе разделения выборки на два непересекающихся класса по плотности строится минимальное интервальное покрытие

значений целевого признака, вычисляется функция принадлежности и показатель устойчивости, не имеющий единиц измерения. Устойчивость интерпретируется как унифицированная мера различия классов, что позволяет проводить содержательный анализ в условиях нечёткости.

Ключевые слова: гибридные модели, нечёткие множества, скрытые закономерности, устойчивость признака, интервальное покрытие, связанность объектов.

Введение

Для решения задачи поиска регрессионной зависимости в данных применяются алгоритмы с использованием метрик (например, метод Надарая–Ватсона). От выбора метрики зависят значения оценок плотности распределения объектов, а также реализация методов кластерного анализа – как на основе плотности, так и на основе топологических свойств объектов [1, 2].

Исследуется связь между оценками плотности объектов по локальным областям и значениями целевого признака этих объектов. Отказ от корреляционной зависимости между плотностью и целевым признаком обусловлен низкой достоверностью усреднённых оценок. Разработана альтернативная методика поиска зависимостей с привлечением методов интеллектуального анализа данных. Доказательной базой для интерпретации служат формальные закономерности (последовательности, гипершары) и критерии получения оптимального решения.

В качестве одного из ограничений предлагается разделение объектов на два непересекающихся класса K_1 и K_2 в соответствии с упорядоченной последовательностью оценок плотности в локальной области фиксированного размера. Принцип деления описан в работе [1]. Такое разделение открывает возможность построения минимального покрытия значений целевого признака непересекающимися интервалами, в каждом из которых доминируют объекты с высокой или низкой плотностью. На основе значений функции принадлежности к классам по интервалам вычисляются характеристики устойчивости. Анализ различий по устойчивости позволяет исследовать влияние различных метрик в регрессии.

Предмет исследования

Актуальность разработки методов объяснимого анализа данных особенно высока в областях, требующих надёжности и проверяемости решений. Современные исследования направлены на интерпретируемость любых выявленных структурных зависимостей. Для этого разрабатываются гибридные модели, объединяющие классификацию, регрессию и кластерный анализ. Базовым показателем для классификации служит обобщающая способность, допускающая содержательную интерпретацию. Классификация на основе значений количественного целевого признака востребована для:

- отбора информативных наборов признаков без регуляризаторов (например, $L1$);
- разбиения объектов на несферические группы по описаниям зависимых признаков; такие группы формируются на основе отношения связности по граничным объектам классов.

Разбиение объектов на классы по оценкам плотности необходимо для:

- анализа связи между плотностью и устойчивостью целевого признака;
- исследования влияния меры расстояния на показатели плотности.

Для иллюстрации рассматривается децильное разбиение: упорядоченная последовательность оценок плотности разбивается на 10 равных частей. Пошаговое формирование бинарных разбиений: в K_1 включаются объекты первого дециля, в K_2 – остальные; затем K_1 расширяется. По набору таких классификаций исследуется устойчивость признаков.

Проверяются следующие гипотезы:

- при выборе радиуса локальной окрестности $\varepsilon(k)$ состав классов K_1 и K_2 меняется;
- существует связь между устойчивостью целевого признака $g(y)$ и составом кластеров, выделенных через граничные объекты;

– существует зависимость между метрической структурой описаний и устойчивостью целевого признака;

– существует контекстная зависимость между значением целевого признака и структурой связности, используемой при кластерном анализе.

Каждый класс может быть представлен как метаобъект в унифицированном пространстве признаков, где множество допустимых значений строго фиксировано и допускает интерпретацию.

Математическая модель

Для описания выборки $E_0 = \{S_1, \dots, S_m\}$ применяется набор признаков $X(n) = (x_1, \dots, x_n)$. Каждому объекту S_i поставлен в соответствие целевой признак y_i , который может быть задан по результатам измерений либо вычислен как оценка плотности $y_i = \varphi(S_i, \varepsilon)$ в локальной области в форме гипершара радиуса ε по метрике $\rho(x, y)$.

Определены процедуры для вычисления:

- радиуса $\varepsilon = \varepsilon(k)$ локальной области методом k ближайших соседей;
- оценки плотности $y_i = \varphi(S_i, \varepsilon)$;
- разбиения E_0 по y_i на непересекающиеся классы K_1, K_2 ;
- количества и состава кластеров несферической конфигурации.

Модель основывается на понятиях связанности объектов, минимального интервального покрытия, функции принадлежности к нечётким множествам и устойчивости признаков.

Объекты $S_u, S_v \in K_i$ считаются связанными $(S_u \leftrightarrow S_v)$, если

$$\{S \in B(E_0, \rho) | \rho(S, S_u) < r_u \text{ and } \rho(S, S_v) < r_v\} \neq \emptyset,$$

где r_u, r_v – расстояния до ближайшего объекта из K_{3-i} , а $B(E_0, \rho)$ – множество граничных объектов. На основе этого строится матрица инцидентий $R = \{r_{ij}\}_{m \times m}$.

Для целевого признака y_i исследуется контекст $O(S_i, N)$ из N ближайших соседей на числовой оси. Анализируется связанность объектов из контекста по матрице R . Наличие связанности выражается тройкой (c_{ik}, p_{ik}, l_{ik}) , где $c_{ik} \in \{0, 1\}$ – индикатор существования цепочки $S_i \leftrightarrow S_v \leftrightarrow S_k$, p_{ik} – минимальное число рёбер, l_{ik} – длина кратчайшего пути. Введём в рассмотрение оценку через $O(S_i, N)$ следующим образом:

$$BAHO(S_i) = \sum_{c_{ik}=1} (1/p_{ik}) / N.$$

Идеальный случай $BAHO(S_i) = 1$ достигается, если все объекты из $O(S_i, N)$ принадлежат одному кластеру и для каждого объекта $S_k \in O(S_i, N)$ гипершар с центром в S_k пересекается с гипершаром с центром в S_i .

Размер локальной области для вычисления плотности методом k ближайших соседей:

$$\varepsilon = \varepsilon(k) = \sum_{i=1}^m d(S_i, k) / m, \text{ где } d(S_i, k) \text{ расстояние от объекта } S_i \text{ до его } k\text{-го ближайшего}$$

соседа.. Оценка плотности:

$$\varphi(S, \varepsilon) = \sum_{\rho(S, S_i) < \varepsilon} \left(1 - \frac{\rho(S, S_i)}{\varepsilon} \right).$$

Математическое ожидание:

$$M(\varepsilon) = \sum_{i=1}^m \varphi(S_i, \varepsilon) / m.$$

Исходный состав классов:

$$K_1 = \{S_j | \rho(S_k, S_j) < \varepsilon \text{ and } \varphi(S_k, \varepsilon) > M(\varepsilon)\} \text{ и } K_2 = E_0 \setminus K_1.$$

Упорядочив значения $y_i = \varphi(S_i, \varepsilon)$ как $r_1, \dots, r_i, \dots, r_m$, разбиваем их на p_c непересекающихся интервалов $[r_u, r_v]^\mu$ по критерию:

$$\left| \frac{d_{1c}(u, v)}{|K_1|} - \frac{d_{2c}(u, v)}{|K_2|} \right| \rightarrow \max,$$

где $d_{1c}(u,v)$, $d_{2c}(u,v)$ – количество объектов K_1 и K_2 в интервале.

Значения признака в границах интервала рассматриваются как градация номинального признака. Функция принадлежности по градации μ :

$$f_c(\mu) = \frac{d_{1c}(\mu)/|F_1|}{d_{1c}(\mu)/|F_1| + d_{2c}(\mu)/|F_2|},$$

устойчивость:

$$g_c = \frac{1}{h} \sum_{\mu=1}^{p_c} \begin{cases} n(\mu) \cdot f_c(\mu), f_c(\mu) \geq 0.5, \\ n(\mu) \cdot (1 - f_c(\mu)), f_c(\mu) < 0.5, \end{cases}$$

где $n(\mu) = d_{1c}(\mu) + d_{2c}(\mu)$. Устойчивость близка к 0.5 при сходстве классов и к 1 при их различии, не имеет единиц измерения и может служить унифицированной мерой.

Рекомендации

Предлагаемая гибридная модель рекомендуется для использования в задачах объяснимого анализа данных в медицине, экономике и технической диагностике, где требуется выявление скрытых закономерностей без потери интерпретируемости. Практическая реализация включает следующие шаги:

1. Выбор метрики и параметра k для оценки локальной плотности.
2. Построение бинарной классификации на основе сравнения плотности с математическим ожиданием.
3. Формирование минимального интервального покрытия значений целевого признака.
4. Вычисление устойчивости интервалов и отбор информативных градаций.
5. Анализ связанности объектов в контексте ближайших соседей по целевой переменной.

Данный подход позволяет снизить влияние произвольного выбора метрики и повысить достоверность выводов в условиях нечёткости исходных данных.

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AFZAL BELGILARNI AJRATISHGA ASOSLANGAN KLASSIFIKATORLAR MODELI

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Annotatsiya. Bu ishda katta o'lchamli belgilar fazosida radial funksiyalarga asoslangan klassifikatorlar modelini qurish masalasi qaralgan. Taklif etilgan klassifikatorlar modelining asosiy g'oyasi afzal belgilar to'plamini ajratib olish va ajratib olingan belgilar to'plamida sinflararo tafovutlarni hisobga olishga asoslangan yuqori samarali klassifikatorlar modelini qurishdan iborat. Eksperimental tadqiqotlar natijasida ushbu modelning ma'lumotlar o'lchamini kamaytirish hamda tanib olish aniqligini oshirishi ko'rsatilgan.

Kalit so'zlar: reprezentativ belgi, afzal belgi, farqlanish funksiyasi, radial funksiyalar, yaqinlik funksiyasi, klassifikator.

1. Kirish

Oxirgi yillarda katta o'lchamli belgilar fazosida berilgan obyektlarni tanib olish va klassifikatsiya qilish bilan bog'liq masalalarni yechish usul va algoritmlarini, hamda mazkur sharoitda klassifikatorlar modelini ishlab chiqishga oid ilmiy nashrlarning soni doimiy ravishda ortib bormoqda. Buning sababi shundaki, ushbu usullar va modellardan foydalanib hal qilinadigan amaliy masalalar doirasi doimiy ravishda kengayib bormoqda [1-3].

Ma'lumki, tibbiy diagnostika, texnik tizimlar holatini nazorat qilish va tasvirlarga ishlov berish kabi sohalarida obyektlarni sinflarga ajratish masalalarda obyektlarni tavsiflovchi dastlabki belgilar soni juda katta bo'lib, ularning ichida ahamiyatsiz, shovqinli va bir-birini takrorlovchi belgilar ko'p uchraydi. Katta o'lchamli belgilar fazosi hisoblash murakkabligini oshiradi va modelning umumlashtirish xususiyatini pasaytiradi [3]. Ushbu muammoni bartaraf etish uchun o'zaro mustaqil va eng informativ belgilarni ajratib olish, ya'ni afzal ko'rilgan belgilar fazosini shakllantirish lozim. Shuning uchun belgilar fazosining katta o'lchami sharoitida tanib olish algoritmlarini ishlab chiqish masalalari dolzarbdir.

2. Masalaning qo'yilishi

Faraz qilaylik, bizga l ta sinfga tegishli bo'lgan S obyektlar to'plami berilgan: $K_1, \dots, K_j, \dots, K_l$. Har bir S ($S \in S$) obyekt katta o'lchamli fazoda n ta belgilar dan iborat vektor ko'rinishida beriladi: $S = (a_1, \dots, a_i, \dots, a_n)$. Masalaning asosiy maqsadi n o'lchamli X belgilar fazosini tahlil qilish orqali kuchli bog'langan belgilarni filtratsiyalash, ular asosida X' reprezentativ belgilar to'plamini va udan eng yuqori dominantlikka ega bo'lgan afzal belgilar fazosini (X'') qurishdan iborat bo'lib, bunda yangi n'' o'lchamli fazoda xatoligi minimal klassifikatorlar modelini qurishdan iborat.

3. Masalani yechish usuli

Masalani yechish uchun radial funksiyalarga asoslangan klassifikatorlar modeli taklif etiladi. Taklif etilayotgan model yettita asosiy bosqichdan iborat:

1-bosqich. Kuchli bog'langan belgilar to'plamlarini ajratish: Dastlabki W ($W = (x_1, \dots, x_i, \dots, x_n)$) to'plami ichidan o'zaro kuchli bog'langan va kesishmaydigan to'plamlar majmuasi aniqlanadi. Bunda $W_{\mathcal{B}} (W_{\mathcal{B}} = \{Q_1, \dots, Q_u, \dots, Q_{n'}\})$ quyidagi shartlarini qanoatlantiradi:

$$\bigcap_{q=1}^{n'} Q_u = \emptyset; \bigcup_{q=1}^{n'} Q_u = W_{\mathcal{B}}; n' = |W_{\mathcal{B}}|.$$

2-bosqich. Reprezentativ belgilar to'plamini shakllantirish: Har bir ajratilgan Q_u to'plamdan eng yaxshi reprezentativ belgilar ega yagona belgi olinib, qisqartirilgan X' ($X' = (x_{i_1}, \dots, x_{i_q}, \dots, x_{i_{n'}})$) fazosi aniqlanadi.

3-bosqich. Afzal belgilar to'plamini ajratish: Belgilarning har bir sinfga nisbatan dominantlik bahosi $\mathfrak{D}_{ij}$ sinflararo variatsiya va sinf ichki variatsiya o'rtasidagi nisbat asosida hisoblanadi.

$$\mathfrak{D}_{ij} = \frac{(2N_2 \sum_{S_u \in CK_j} \sum_{S \in K_j} Q_i(a_{iu}, a_i))}{(N_1 \sum_{S_u \in CK_j} \sum_{S \in K_j} Q_i(a_{iu}, a_i))},$$

bu yerda $Q_i(x, y)$ - bir o'lchamli masofa funksiyasidir. Baholash natijasida eng katta dominantlik qiymatiga ega bo'lgan belgilarga yuqori afzallik beriladi va har bir sinf uchun afzal belgilar to'plami X'' tuziladi:

$$X'' = (x_{i_1}, \dots, x_{i_q}, \dots, x_{i_{n''}}).$$

4-bosqich. Obyektlar o'rtasidagi farqlanish funksiyasini aniqlash. Yangi X'' fazoda obyektlar orasidagi farq o'lchovi kiritiladi:

$$d(S_u, S) = \sum_{q=1}^{n^n} \lambda_q \mathfrak{Q}_q(a_{iu}, a_i),$$

bu yerda λ_q – tegishli belgining ahamiyatlilik darajasini ko'rsatuvchi noma'lum koeffitsiyent bo'lib, $\mathfrak{Q}_q$ – esa yarim-metrika funksiyasi hisoblanadi.

5-bosqich. Umumlashgan farqlanish funksiyasini aniqlash. K_j sinf bilan S obyekt o'rtasidagi umumlashtirilgan farq quyidagicha funksiyasini aniqlanadi:

$$D(K_j, S) = \sum_{S \in K_j} \gamma_q d(S_u, S),$$

bu yerda $\gamma_q - S_u$ obyektning o'quv tanlanmadagi muhimlik parametridir.

6-bosqich. Yaqinlik funksiyasini aniqlash. Radial funksiyalar asosida K_j sinf bilan S obyekt o'rtasidagi yaqinlik bahosi quyidagicha hisoblanadi:

$$R(K_j, S) = 1/(1 + \tau D(K_j, S)).$$

7-bosqich. Umumlashgan yaqinlik funksiyasi. Ma'lum bir sinfga maksimal yaqinlik va qolgan sinflardan uzoqlikni ta'minlovchi yakuniy baho quyidagicha hisoblanadi:

$$B(K_j, S) = b'_j R(K_j, S) - \sum_{\substack{u=1 \\ u \neq j}}^l c'_u R(K_u, S).$$

Shunday qilib, afzal belgilarni ajratishga asoslangan klassifikatorlar modelini aniqladik. Ushbu modeldagi har qanday klassifikator $\tilde{\pi}$ parametrlar to'plamini berish orqali to'liq aniqlanadi. Taklif etilgan modeldagi barcha klassifikatorlari to'plamini $\mathfrak{K}(\tilde{\pi}, S)$ bilan belgilaymiz. Ko'rib chiqilayotgan model doirasida eng yaxshi klassifikatorni aniqlash $\tilde{\pi}$ parametrlar fazosida amalga oshiriladi. Eng yaxshi $\mathfrak{K}(\tilde{\pi}_0, S)$ klassifikatorni qurish sifat funksiyasining minimal qiymatini izlash asosida tanlanadi:

$$\begin{aligned} \mathcal{R}(\tilde{\pi}, \tilde{S}^m) &= \Theta(\mathfrak{K}(\tilde{\pi}, \tilde{S}^m))/m, \\ \Theta(\mathfrak{K}(\tilde{\pi}, \tilde{S}^m)) &= \left(\sum_{S \in \tilde{S}^m} \mathfrak{Q}(\|\tilde{\alpha}(S) - \mathfrak{C}(\mathfrak{K}(\tilde{\pi}, S))\|) \right), \\ m &= |\tilde{S}^m|, \quad \mathfrak{Q}(x) = \begin{cases} 1, & \text{agar } x = 0; \\ 0, & \text{agar } x \neq 0, \end{cases} \end{aligned}$$

bunda $\|\cdot\|$ – mantiqiy vektor normasi.

Ko'rib chiqilayotgan klassifikatorlar modelining ishga yaroqli ekanligini tekshirish uchun eksperimental tadqiqotlar o'tkazish kerak.

4. Eksperimental tekshirish

Taklif etilgan modelini ishga yaroqli ekanligini tekshirish uchun 120 ta dastlabki belgiga ega bo'lgan ma'lumotlar bazasida sinab ko'rildi. Birinchi va ikkinchi bosqichlar natijasida belgilar soni n' ($n' = 45$) tagacha qisqartirildi. Dominantlik baholari asosida eng afzal deb topilgan n'' ($n'' = 16$) ta belgi ajratib olindi. Natijada belgilar fazosi o'lchami 87% ga kamaydi, bu esa klassifikatorning ishlash vaqtini 6 barobardan ko'p tezlashtirdi. Shu bilan birga, shovqinli belgilarning chiqarib tashlanishi evaziga tanib olish aniqligi (Accuracy) 86.6% dan 94.3% gacha ko'tarildi.

Xulosa

Afzal ko'rilgan belgilar fazosida klassifikatorlarni qurish katta o'lchamli ma'lumotlar bilan ishlashda yuqori samaradorlik beradi. Taklif etilgan klassifikatorlar modeli katta o'lchamli belgilar fazosida klassifikatsiya muammosini muvaffaqiyatli hal etadi, hamda tanib olish tezligi va tanib olish aniqligi an'anaviy usullarga nisbatan bir-necha barobarga ortdi.

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KVANT HISOBLASH VA GENETIK ALGORITMLAR ASOSIDA TASVIR SEGMENTATSIYASI

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Annotatsiya. Ushbu ishning asosiy maqsadi – genetik algoritmlar va kvant hisoblash texnologiyalarini birlashtirish orqali tasvir segmentatsiyasini samarali amalga oshiruvchi innovatsion usulni taklif etish va uni baholashdir. An'anaviy va kvant yondashuvlarini kombinatsiya qilish orqali tasvirni aniq va tezkor segmentatsiya qilish, kvant kernel usullari yordamida klassifikatsiya sifatini oshirish, shuningdek, genetik algoritmlar yordamida kvant sxemalarni optimallashtirish ushbu tadqiqotning asosiy yo'nalishlari hisoblanadi.

Ushbu tadqiqot natijalari kvant hisoblash va sun'iy intellekt sohasida yangi tadqiqotlar uchun asos bo'lib xizmat qilishi mumkin hamda tasvirlarni qayta ishlash jarayonlarida kvant algoritmlarining amaliy qo'llanilishi bo'yicha yangi yo'nalishlarni ochib berishi mumkin. Klassik hisoblashdagi bitlarga o'xshab, kvant bit yoki qubit kvant ma'lumotlarining eng kichik birligidir. Kubit – bu ikki xil kvant holatining superpozitsiyasida mavjud bo'lishi mumkin bo'lgan fizik yoki mantiqiy tizim. Bu holatlar odatda 0 va 1 deb belgilanadi va Dirac raqamlar tizimida Hilbert fazosida ikkita vektor sifatida belgilanadi [1,2]:

Kubitning umumiy holati bu ikki imkoniyatning $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$ murakkab amplituda α bilan kvant β superpozitsiyasi va Murakkab amplituda bizga ehtimollarni beradi. $|\alpha|^2$ va $|\beta|^2$ qubitni o'lchashda mos ravishda $|0\rangle$ va $|1\rangle$ ni aniqlash uchun $|\alpha|^2 + |\beta|^2 = 1$.

Asosiy jarayonlar quyidagilardan iborat [3-6]:

1. Tasvirni oldindan qayta ishlash

Agar tasvir $I_N(x, y)$ piksel qaymatlaridan tashkil topgan bo'lsa, uni 0 dan 1 gacha normallashtiramiz

$$I_N(x, y) = \frac{I(x, y)}{255},$$

bu yerda $I_N(x, y)$ – normallashtirilgan tasvir, $I(x, y)$ – dastlabki tasvirning piksel qiymati.

2. Tasvir segmentatsiyasi

Otsu bo'sag'aing segmentatsiya usuli tasvirdagi piksel yorqinligi histogrammasi bo'yicha eng yaxshi chegaraviy qiymat T ni tanlash orqali tasvirni ikkita sinfga ajratadi. Otsu mezoniga ko'ra, optimal T quyidagidek bilan topiladi:

$$\sigma_B^2(T) = \omega_1(T)\sigma_1^2(T) + \omega_2(T)\sigma_2^2(T),$$

bu yerda $\omega_1(T)$ va $\omega_2(T)$ – har bir sinfnig ehtimollik massasi, $\sigma_1^2(T)$ va $\sigma_2^2(T)$ – har bir sinfnig dispersiyasi, $\sigma_B^2(T)$ – chegaraning ajratish qobiliyatini o'lchaydigan metrikadir. Optimal T quyidagi shart asosida aniqlanadi:

$$T^* = \arg \max_T \sigma_B^2(T)$$

Tasvir chetlarini aniqlash uchun Canny operatori gradientni hisoblashdan foydalanadi:

$$G(x, y) = \sqrt{G_x^2 + G_y^2},$$

bu yerda G_x va G_y – Sobel filtr maskalari.

3. Dataset yaratish va kvant kernel yordamida tasniflash

Har bir piksel uchun xarakteristik vektor olidadi:

$$X = [R, G, B],$$

bu yerda R, G, B – rang komponentlari. Yig'ilgan ma'lumotlar Quantum Support Vector Classification (QSVC) model bilan tasniflanadi.

Kvant kernel usuli piksel xususiyatlarini kvant holatlarga xaritalash orqali bajariladi.

$$\Phi(x) = U(x)|0\rangle,$$

bu yerda $U(x)$ – kvant sxema bo'lib, u kiruvchi x ma'lumotlar bo'yicha kvant vektor hosil qiladi. Kvant kernel quyidagicha ifodalanadi:

$$K(x_i, x_j) = \left| \langle \Phi(x_i) | \Phi(x_j) \rangle \right|^2,$$

bu yerda $K(x_i, x_j)$ – x_i va x_j orasidagi kvant o'xshashlik. Fidelity Quantum Kernel metodi ushbu hisob-kitobni bajaradi.

QSVC kvant kernel asosida quyidagi optimallashtirilgan SVM muammosini hal qiladi:

$$\min \frac{1}{2} \sum_{i,j} \alpha_i \alpha_j y_i y_j K(x_i, x_j) - \sum_i \alpha_i,$$

bu yerda α_i – Lagrange koeffitsientlari, y_i – piksellar yorlig'i (segmentatsiya natijasi).

4. Genetik algoritmlar bilan kvant sxema optimallashtirish

Har bir kvant sxema genetik kod sifatida yozadi:

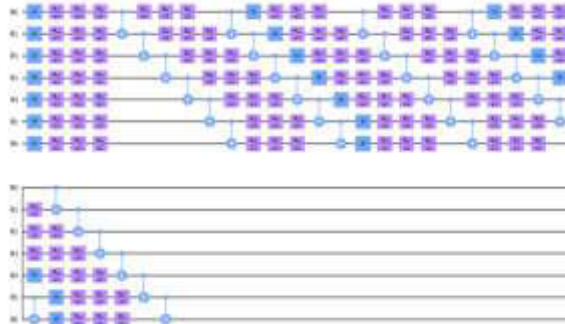
$$I = [g_1, g_2, \dots, g_n],$$

bu yerda g_i – kvant darvoza turi (Hadamard, RX, RY, RZ, CNOT va h.k.).

Genetik algoritm kvant sxemani optimallashtirish uchun fitness funksiyadan foydalanadi:

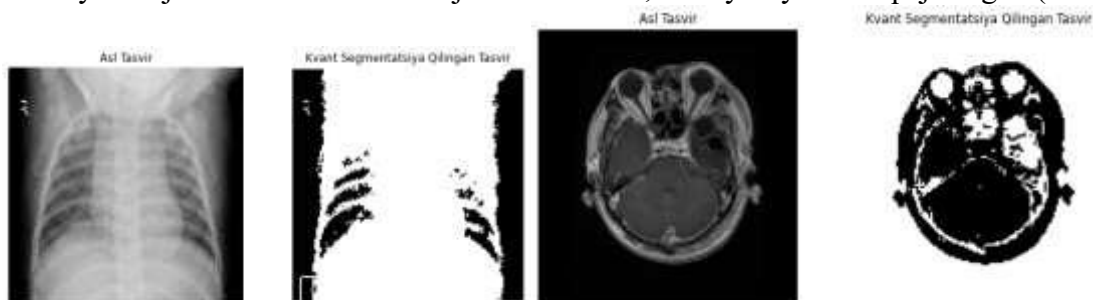
$$F(I) = A(I) - \lambda C(I)$$

bu yerda $A(I)$ – QSVC modelining tasniflash aniqligi, $C(I)$ – kvant sxema murakkablighi (darvoza soni), λ – jarima koeffitsienti. Kvant sxemasi 1-rasmda keltirilgan.



1-rasm. Kvant sxemasi

Asl tasvir va segmentlangan tasvir birga chiqarilganida, chetlar yaxshi ajratilganini va segmentatsiya to'g'ri bajarilganini ko'rish mumkin bo'ldi. Murakkab fonli tasvirlarda segmentatsiya natijalarida xatoliklar mavjud bo'lsa ham, asosiy obyekt aniq ajratilgan (2-rasm).



2-rasm. Dastur natijalari

Quantum Support Vector Classifier (QSVC) modeli yordamida tasniflash bajarildi. Klassifikatsiya aniqligi: Kvant kernel bilan 91.2%, Klassik SVM bilan 87.5%. O'quv to'plamida QSVC modeli yaxshi natija ko'rsatdi. Sinov to'plamida ham kvant kernel ishlatilganda an'anaviy SVM modeliga nisbatan yaxshiroq natijalar olindi (1-jadval).

1-jadval

Umumiy natijalar va solishtirma tahlil

Model	Aniqlik	Murakkablik
	k	ik
Klassik SVM (RBF Kernel)	87.5	—
Kvant QSVC (Fidelity Kernel)	91.2	25

Genetik Optimallashtirilgan Kvant Sxema	Algoritm Orqali	92.3	18

Segmentatsiya natijalari yuqori aniqlikka ega bo'ldi (85–91%), va ayniqsa kvant tasniflash modelidan foydalanilganda yaxshilandi.

Ushbu ishda kvant hisoblash va genetik algoritmlar asosida tasvir segmentatsiyasi va tasniflash modelini yaratish bo'yicha tadqiqot olib borildi. Dastur yordamida tasvir segmentatsiyasi, kvant kernel asosida tasniflash va genetik algoritmlar orqali kvant sxemalarni optimallashtirish amalga oshirildi. QSVC kvant modeli klassik SVM bilan solishtirganda aniqroq natija berdi, bu kvant kernelning samarali ekanligini ko'rsatdi. Genetik algoritm kvant sxemalarni optimallashtirishga yordam berdi, aniqlikni oshirish bilan birga kvant darvozalari sonini kamaytirdi. Tizim real kvant kompyuterlarga moslashtirilsa, yanada samaraliroq natijalarga erishish mumkin, ayniqsa NISQ (Noisy Intermediate-Scale Quantum) kvant protsessorlar bilan sinab ko'rilganda. Ushbu ish kvant hisoblash va genetik algoritmlarning kombinatsiyasi tasvirni qayta ishlash jarayonlarini optimallashtirishda istiqbolli yo'nalish ekanligini tasdiqlaydi. Kelajakdagi tadqiqotlarda real kvant protsessorlar va murakkab tasvir tahlili algoritmlarini qo'llash orqali yanada yuqori aniqlik va samaradorlikka erishish mumkin.

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TASVIRLARDAGI BELGI SHAKLLANTIRISH ALGORITMLARI

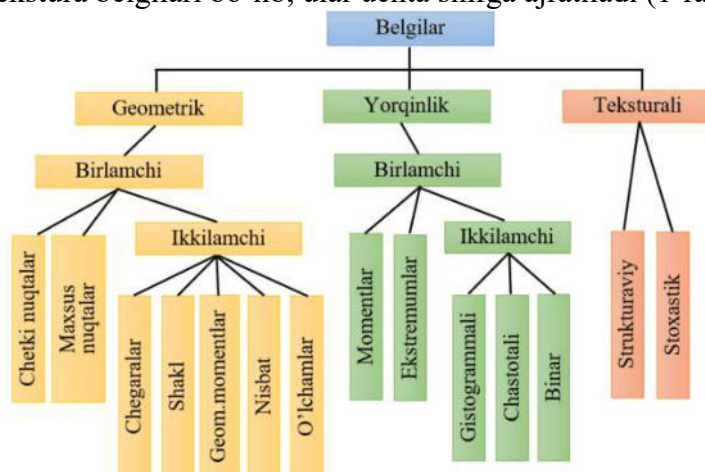
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Annotatsiya. Tasvirlardagi obyekt belgilarini shakllantirish tasvirlarni tanib olishdagi o'ta muhim bosqich hisoblanadi. Chunki tasvirdagi ob'ektni uning belgilariga tayangan holda aniqlash orqali tanib olish tezligi va aniqligini oshirish mumkin. Bunda tasvirdagi o'rganilayotgan ob'ekt aprior ma'lumotlarga asoslangan belgilar vektori ko'rinishida ifodalanadi va olingan belgilar to'plamidan ob'ektlarni tanib olish hamda ularni tasniflashda foydalaniladi. Tasvirlarni tanib olish tizim sifatida ob'ektni tavsiflovchi belgilarni qanchalik to'g'ri aniqlanganligiga bog'liq. Biroq, ayni paytda tasvirni tavsiflash yoki belgilar to'plamini shakllantirish jarayoni hali ham ishlab chiquvchilar tajribasi va malakasiga bog'liq jarayon hisoblanadi. Bundan tashqari, belgi shakllantirishni mavjud algoritmlari tasvir turlarini barchasi uchun universal emas.

Belgi shakllantirish-bu tasvir qiziqish maydonini, ya'ni ob'ektni ixcham belgilar vektori sifatida samarali ifodalovchi va tasvirni qayta ishlanuvchi ma'lumotlar miqdorini kamaytirish imkonini beruvchi yondashuv hisoblanadi. Ayniqsa, ushbu yondashuv tasvir o'lchamlari katta bo'lganda yoki tasvirlarni qayta ishlash tizim tezkorligini oshirishda foydalidir.

Belgilar tasvirlardagi ob'ektlarni tavsiflovchi muhim elementlardir, ya'ni bunda ob'ekt ba'zi global va lokal belgilar bilan tavsiflanadi. Ob'ektni belgilar soni ob'ekt aniqlangan belgi maydoni o'lchamini belgilaydi. Global belgilar ob'ektni sahnadagi barcha boshqa ob'ektlardan ajratib turadi, lokal belgilar esa ob'ektni sahnadagi joylashishini aniqlaydi. Shakllantirilgan belgilar vektori miqdoriy yoki sifat belgilaridan tashkil topgan bo'lishi mumkin. Miqdoriy belgilar raqamli qiymatlar bilan tavsiflanadi, sifat belgilar esa inson tomonidan belgilanadi va u ko'pincha sub'ektivdir. Raqamli tasvirlardagi ob'ekt belgilari birlamchi va ikkilamchi turlarga ajratish mumkin. Birlamchi belgilar raqamli tasvir yordamida hisoblangan belgilar bo'lsa, ikkilamchi belgilar odatda birlamchi belgilar asosida hisoblanadi. Raqamli tasvirlardagi ob'ekt belgilari geometrik, yorqinlik va tekstura belgilari bo'lib, ular uchta sinfga ajratiladi (1-rasm).



1-rasm. Belgilar vektori

Yuqoridagi rasmda keltirib o'tilgan har bir belgi turi bo'yicha ma'lumotlar quyida batafsil keltirilgan.

Geometrik belgilar lokal hisoblanadi va ob'ekt tasviri etarli darajada bir xil bo'lib, birlamchi geometrik belgilarni ko'rish va hisoblash imkonini beradi deb taxmin qilinadi. Asosiy geometrik belgilarga ob'ekt chegarasi, chiziq qismi, burchak, chiziqlarni T-, Y-, L shaklidagi ulanishi, chiziq boshi va oxiri, nuqta (hudud), ob'ekt qavariqligi yoki botiqligi kabilar misol bo'ladi. Ikkilamchi belgilar esa maydon, berilgan nuqtalar orasidagi masofa, perimetr kabilar bo'lishi mumkin. Ob'ektlar o'ziga xos geometrik maxsus nuqtalarga ega bo'lishi mumkin. Masalan, to'rtburchakni maxsus nuqtalari uni to'rtta uchi, to'rtburchakni tomoni esa ikki uchi orqali o'tuvchi kesmadir. Tasvirdagi ob'ektlar maxsus nuqtalaridan biri ob'ekt figurasi chegara nuqtalaridir. Odatda ikkilamchi belgilar maxsus nuqtalar asosida shakllantiriladi. Ob'ekt qirralari uning chegaralarini tashkil qiladi. Ob'ekt chegaralari - uni shaklini tavsiflovchi ob'ekt kontur chiziqlaridir [1]. Bu belgidan ob'ekt o'lchami, shakli va yo'nalishi kabi geometrik belgilarni hisoblashda foydalaniladi. Chegaralar ikkinchi darajali belgilardir. Ob'ekt shakli ob'ekt konturi va chegaralari bilan belgilanadi [1] va u teshiklarni mavjudligi, maydon perimetriga munosabati, cho'zilishi va yumaloqligi bilan tavsiflanadi. Jism shaklini aniqlaydigan geometrik belgilar perimetri, maydoni, minimal va maksimal radiuslari, burchaklari, jismni yumaloqlik darajasi, egriligi, ob'ektni simmetriya darajasidan iborat. Shakl ikkinchi darajali belgidir. Ob'ekt o'lchamlari. O'lchov belgilariga ob'ekt piksellar soni, uzunligi, kengligi va o'lchamlari kabilar kiradi [2]. Ushbu belgilardan foydalanish rangli, kulrang va ikkilik tasvirlarga tegishli. Bu belgilar tasvir lokal energiyasidagi o'zgarish va tashkil etuvchi piksellar yorqinligidagi farqlarni tavsiflaydi. Ekstremum - bu tasvirdagi piksel yoki piksellarni maksimal yoki minimal qiymati. Agar u butun tasvir bo'yicha hisoblangan bo'lsa, u holda bu global, agar u tasvir maydonida hisoblangan bo'lsa, u lokal hisoblanadi. Ekstremumlar birlamchi belgilardir. Ba'zi almashtirishlar chastota belgilarini hisoblashi mumkin bo'lgan tasvirni chastotali tasvirini shakllantirishga imkon beradi. Qirra va chegaralarni aniqlashda yuqori chastotali belgilar qo'llaniladi, yo'nalishni aniqlashda esa burchaklardan foydalaniladi va ular ikkilamchi belgilar hisoblanadi. Gistogramma belgilari statistik xususiyatga ega va tasvir yorqinligi taqsimotini tavsiflaydi. Ushbu turdagi belgilar o'rta qiymat,

standart og'ish, buzilish, energiya va entropiyadan iborat. Gistogramma belgilari ikkilamchi belgilardir.

Faraz qilaylik, manfiy bo'lmagan $t(\alpha, \beta)$ funktsiya berilgan bo'lsin. Ushbu funktsiya ostidagi hajm birlikka teng bo'lishi uchun normallashtirilgan. Momentlar birlamchi belgilardir. Ikki o'zgaruvchili $t(\alpha, \beta)$ funktsiyani l_{pq} momenti quyidagicha aniqlanadi:

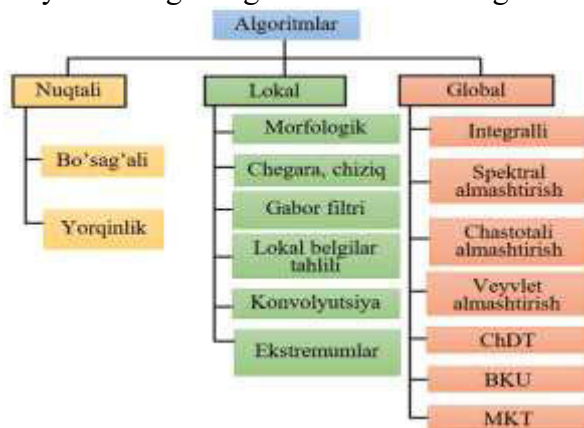
$$l_{pq} = \int \int \alpha^p \beta^q t(\alpha, \beta) d\alpha d\beta,$$

bu erda p, q - manfiy bo'lmagan butun sonlar, $(p+q)$ esa moment tartibi.

Teksturalar qum, don, o't va mato kabi turli xil tasvirlarda uchraydi va ular qo'pol, qalin, xira, donador, muntazam, tartibsiz, chiziqli bo'lishi mumkin. Teksturalar odatda tuzilmaviy va stoxastik turlarga ajratiladi [2]. Tekstura belgilarini 28 ta to'plami [1] ishda keltirilgan. Ikkilik belgilar faqat ikkita qiymatga ega bo'lishi mumkin, masalan, 0 yoki 1. Ikkita ikkilik belgini taqqoslaganda belgi qiymatlari mos yoki mos emasligi haqida yagona xulosa chiqarish mumkin. Ikkilik belgilar binar, mantiqiy va dixotomiya deb ham ataladi.

Belgilarni hisoblash algoritmlar tasnifi. Belgi shakllantirish algoritmlari turli adabiyotlarda turlicha tasniflanadi. Biroq, ushbu ishda 1-rasmdagi kabi tasniflash amalga oshirilgan. Nuqtaga asoslangan belgilarni hisoblash algoritmlari boshqalarni inobatga olmagan holda manba tasviridagi alohida piksellar qiymatlaridan foydalanadi. Algoritm tasvirdagi bir piksel qiymatidan foydalanib belgilarni hisoblaydi. Bo'sag'aga asoslangan algoritmlar ma'lum bir qiymat bilan belgilangan diapazondagi piksellarni tanlaydi. Agar ob'ekt yorqinlik darajasi ma'lum bo'lsa, uni aniqlashda foydalanish mumkin.

Lokal belgilarni hisoblash algoritmlari tasvir mintaqasi piksel qiymatlaridan foydalanadi. Masalan, belgilarni hisoblashda keng tarqalgan niqob amallari ko'pincha 3×3 dan 5×5 pikselgacha bo'lgan o'lchamdagi tasvir mintaqalaridan foydalanadi. Misol sifatida konvolyutsiya Sobel, Prewitt, Robinson va Laplacian niqoblari keltirish mumkin. SUSAN algoritmi ham lokal algoritmlarga tegishli, chunki u funktsiyalar mavjudligini aniqlovchi yorqinlik o'zgarishlari uchun tasvir maydoni tekshiriladigan tasvir qo'shnisidan foydalanadi. Maksimal va minimal qiymatlarni hisoblaydigan operatorlar ham lokal algoritmlardir. Belgilarni hisoblash uchun global algoritmlar asl tasvirni barcha piksellari qiymatlaridan foydalanadigan algoritmlarni o'z ichiga oladi.



2-rasm. Belgi hisoblash algoritmlar tasnifi

Karxunan Lozve almashtirishi bosh komponent usuli (BKU) bo'lib, signalni o'zaro erkin koeffitsientlar to'plamiga aylantiradi. Chiziqli diskriminant tahlil (ChDT) o'lchamlarni kamaytirish va ma'lumotlarni tasniflashda qo'llaniladi. Mustaqil komponentlar tahlili (MKT) aralash signallarni ajratishga mo'ljallangan bo'lib, u statistik taqsimotni birinchi va ikkinchi tartib momentlariga qo'shimcha yuqori tartibli momentlarni dekorrelyatsiyalash orqali statistik jihatdan erkin bo'lmagan Gauss komponentlarini shakllantiradi. MKTni amalga oshirishni FastICA, Infomax va JADE kabi turlari mavjud. Veyvlet almashtirishlar ob'ekt belgilarini hisoblash imkonini beradi. Burchak koordinatalari ob'ekt kontur funktsiyasini bir o'lchovli veyvlet almashtirishi orqali hisoblash tadqiqot ishida amalga oshirilgan. Veyvlet almashtirishdan foydalanishga asoslangan kulrang tasvirlarda burchak detektori ishda taqdim etilgan. Algoritm burchak va ba'zi chegara nuqtalar

joylashuvi shkalasiga proporsional bo'lgan veyvlet almashtirish amplitudasini hisoblaydi [3-4].

Tahlillar shuni ko'rsatdiki, universal belgi shakllantirish algoritmi mavjud emas va algoritmi tanlovi tasvir turi, ob'ekt xususiyati hamda amaliy vazifaga bog'liq holda amalga oshiriladi. Ayniqsa, yuqori aniqlik talab qilinadigan kompyuter ko'rish tizimlarida lokal va global belgilarni birgalikda qo'llash samaradorlikni oshiradi.

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TASVIRLARDAGI BEGONA O'TLARNI ANIQLASH UCHUN ENTROPIK THRESHOLDING USULLARI TAHLILI

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Annotatsiya. Zamonaviy aniq dehqonchilik tizimlarida begona o'tlarni avtomatik aniqlash hosildorlikni saqlash va selektiv gerbitsid qo'llashning asosiy shartlaridan biri hisoblanadi. Ushbu jarayonning dastlabki bosqichi bu tasvirni tuproq, ekin va begona o't kabi sinflarga segmentatsiyalashdan iborat. Mazkur maqolada tasvirni segmentatsiyalash uchun qo'llaniladigan asosiy bo'sag'aviy usullari (Otsu, Kapur entropiyasi va Tsallis entropiyasi) kompleks tahlil qilinadi. Ularning matematik asoslari, afzalligi va kamchiliklari ko'rib chiqiladi hamda dala tasviri ustida amaliy tajriba o'tkazilib, natijalar IoU va Dice metrikalari yordamida baholanadi.

Kalit so'zlar: *tasvirni segmentatsiyalash, thresholding, Otsu usuli, Kapur entropiyasi, Tsallis entropiyasi, begona o't aniqlash, aniq dehqonchilik.*

Tasvirni segmentatsiyalash zamonaviy kompyuter ko'rishi tizimlarining asosiy komponentlaridan biri hisoblanadi. Aniq dehqonchilikda begona o'tlarni aniqlash, selektiv gerbitsid qo'llash va hosildorlikni monitoring qilish uchun keng qo'llaniladi[1]. Biroq dala tasvirlari ko'pincha shovqin, yorug'lik o'zgarishi, tekstura murakkabligi va sinflar (tuproq, ekin, begona o't) intensivliklarining qisman ustma-ust tushishi kabi muammolar bilan tavsiflanadi[2]. Shu sababli oddiy bo'sag'aviy segmentatsiya usullari turli optimallashtirish mezonlari asosida ishlab chiqilgan.

Otsu usuli. Otsu usuli sinflar oraliq dispersiyani maksimallashtirishga asoslanadi[3]. t chegara bo'yicha tasvir piksellari ikkita sinfga ajratiladi va maqsad funksiya quyidagicha aniqlanadi:

$$\sigma_B^2(t) = \omega_0(t)\omega_1(t) [\mu_0(t) - \mu_1(t)]^2 \quad (1)$$

Bu yerda $\omega_0(t)$, $\omega_1(t)$ – sinflarning vaznlari, μ_0 , μ_1 – sinflar ichidagi o'rtacha intensivliklar. Optimal chegara $t^* - \sigma_B^2(t)$ funksiyani maksimum qiluvchi qiymat. Otsu hisoblash jihatdan tejamli, lekin histogrammi multimodal yoki shovqinli tasvirlarda samaradorligi pasayadi.

Kapur entropiyasi. Kapur usuli Shannon entropiyasiga asoslanib, har ikkala sinf ichidagi axborot miqdorini maksimallashtiradi[4]:

$$H_K(t) = H_A(t) + H_B(t) \rightarrow \max \quad (2)$$

Bu yerda $H_A(t)$, $H_B(t)$ – chegaragacha va chegaradan keyingi sinflar ichidagi Shannon entropiyalari. Otsudan farqli ravishda, Kapur usuli axborot nazariyasi nuqtai nazaridan eng

informativ bo‘linishni izlaydi va past chastotali kichik sinflarga (kichik begona o‘t klasterlari) nisbatan sezgirroq hisoblanadi.

Tsallis entropiyasi. Tsallis entropiyasi Shannon entropiyasining umumlashmasi bo‘lib, q parametri orqali boshqariladi[5]:

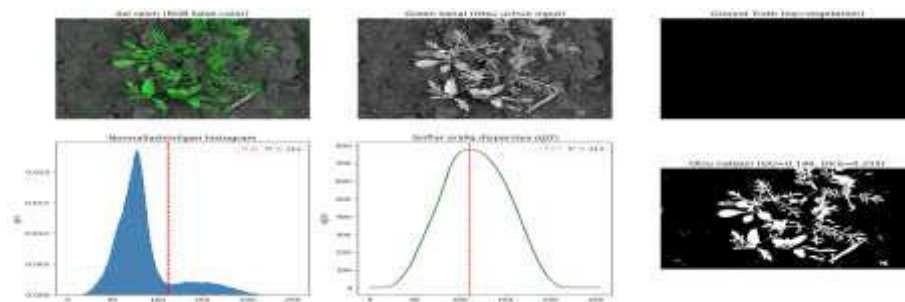
$$S_q(P) = \frac{1 - \sum_{i=1}^n p_i^q}{q-1} \quad (3)$$

Tsallis-thresholding maqsad funksiyasi psevdoaditivlikka asoslanadi:

$$S_q^A(t) + S_q^B(t) + (1-q)S_q^A(t)S_q^B(t) \rightarrow \max \quad (4)$$

Parametr $q < 1$ kam ehtimolli hodisalarga (kichik begona o‘tlar) ko‘proq og‘irlik beradi, $q > 1$ esa katta bir tekis sohalarga sezgirroq. $q \rightarrow 1$ limitda Tsallis Shannon entropiyasiga aylanadi[6]. So‘nggi tadqiqotlarda Tsallis usulining metaevristik algoritmlar (Firefly, Grey Wolf, Whale Optimization) bilan birlashtirilgan kengaytirilgan variantlari taklif etilmoqda[7], [8].

Amaliy olingan natijalar. Amaliy tajribada dala tasviri qo‘llanildi. Tasvir uchta sinfdan iborat: tuproq, ekin va begona o‘t. Gauss shovqini qo‘shilib, qiyinchilik darajasi modellashtirildi.

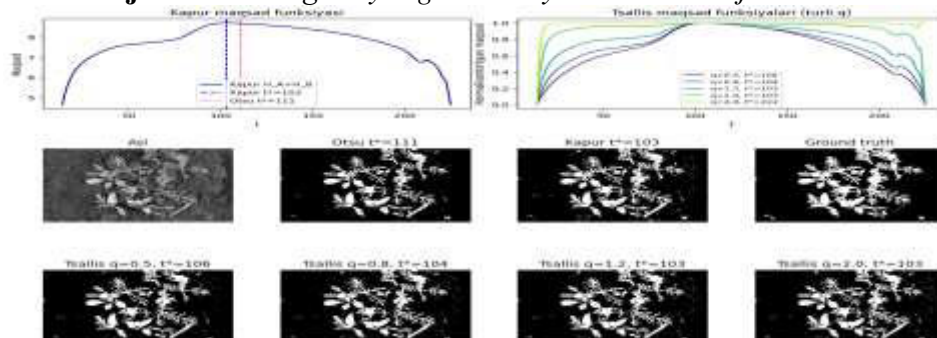


1-rasm. Otsu segmentatsiyasi: histogram, $\sigma_B^2(t)$ egri chizig‘i va natija.

Tasvirda Otsu, Kapur va Tsallis usullari ($q \in \{0.5, 0.8, 1.2, 2.0\}$) qo‘llanildi. Segmentatsiya sifati IoU (Intersection over Union) va Dice koeffitsienti orqali baholandi.

Usul	t^*	IoU	Dice
Otsu	111	0.7268	0.8418
Kapur (Shannon)	103	0.7483	0.8560
Tsallis ($q = 0.5$)	106	0.7461	0.8546
Tsallis ($q = 0.8$)	104	0.7484	0.8561
Tsallis ($q = 1.2$)	103	0.7483	0.8560
Tsallis ($q = 2.0$)	103	0.7483	0.925

1- jadval. Bo‘lag‘aviy segmentatsiya usullari natijalari.



2-rasm. Kapur va Tsallis maqsad funksiyalari va segmentatsiya natijalari (turli q).

Tajriba natijalariga asosan, real dala tasvirida Tsallis entropiyasi $q = 0.8$ parametri bilan eng yuqori natija (IoU = 0.748) ko‘rsatdi. Kapur usuli ham deyarli bir xil natija (IoU = 0.748) berdi,

Otsu esa biroz past ($IoU = 0.727$) qoldi. Bu entropik usullarning murakkab, ko'p tepali histogramlarda Otsudan ustunligini tasdiqlaydi.

Shu bilan birga, barcha bir o'lchovli usullar begona o't va ekin sinflarini bir-biridan ajrata olmadi. Histogramda ularning yuqorisi qisman ustma-ust tushadi va bitta chegara bilan ajratish mumkin emas. Bu esa bir o'lchovli thresholdingning fundamental cheklovi bo'lib, yechim sifatida ikki o'lchovli (2D) histogramga asoslangan kengaytmalar (Abutaleb modeli) va multi-level thresholding metaevristik algoritmlar bilan birlashtirilgan holda tavsiya etiladi[9].

Xulosa. Ushbu tadqiqotda Otsu, Kapur va Tsallis entropiyasi usullarining matematik asoslari va amaliy samaradorligi tahlil qilindi. Real dala tasvirida Tsallis ($q = 0.8$) va Kapur usullari Otsudan yuqori natija ($IoU = 0.748$ vs 0.727) ko'rsatdi. Biroq barcha 1D usullar ekin va begona o'ni bir-biridan ajrata olmasligi fundamental cheklov bo'lib, 2D entropik va multi-level metaevristik yondashuvlar muhim ahamiyatga ega hisoblanadi.

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KIBERXAVFSIZLIKDA SIMMETRIK SHIFRLASH ALGORITMLARINING O'RNI VA QO'LLANILISHI

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Annotatsiya - Raqamli texnologiyalar hayotning barcha sohalariga chuqur kirib borayotgan bugungi davrda axborot xavfsizligini ta'minlash masalasi dolzarb ilmiy va amaliy muammolardan biriga aylandi. Elektron ma'lumotlar almashinuvi, bulutli texnologiyalar, internet xizmatlari va mobil platformalarning ommalashuvi kiberhujumlar sonining ortishiga sabab bo'lmoqda. Bunday sharoitda kriptografik himoya usullari, ayniqsa simmetrik shifrlash algoritmlari ma'lumotlar maxfiylikni saqlashning muhim vositasi hisoblanadi. Mazkur tezisda simmetrik kriptografiyaning nazariy asoslari, AES, DES va Blowfish kabi algoritmlarning ishlash tamoyillari hamda ularning kiberxavfsizlik tizimlaridagi o'rni tahlil qilingan. Shuningdek, AES algoritmi asosida shifrlash

jarayonining matematik modeli yoritilib, uning amaliy qo'llanish sohalari va afzalliklari ko'rib chiqilgan.

Kalit so'zlar: kiberxavfsizlik, kriptografiya, simmetrik shifrlash, AES, DES, Blowfish, axborot xavfsizligi, matematik model, shifrlash algoritmlari.

Kirish. Axborot texnologiyalarining jadal rivojlanishi bilan bir qatorda axborot xavfsizligiga tahdid soluvchi omillar ham ko'payib bormoqda. Internet orqali amalga oshiriladigan moliyaviy operatsiyalar, davlat axborot tizimlari, elektron hukumat platformalari va korporativ tarmoqlarda katta hajmdagi maxfiy ma'lumotlar qayta ishlanadi. Ushbu ma'lumotlarning noqonuniy qo'lga kiritilishi yoki o'zgartirilishi iqtisodiy zarar, shaxsiy ma'lumotlarning oshkor bo'lishi va tizimlar faoliyatining izdan chiqishiga olib kelishi mumkin.[1; 3-5-b.]

Kiberxavfsizlik ana shunday tahdidlardan himoyalashga qaratilgan mexanizmlar va texnologiyalar majmuasidir. Mazkur sohada kriptografiya alohida o'rin egallaydi. Kriptografiya ma'lumotni shifrlash orqali uni faqat ruxsat etilgan foydalanuvchi uchun tushunarli ko'rinishda saqlash imkonini beradi.

Kriptografik tizimlar asosan simmetrik va assimetrik usullarga bo'linadi. Simmetrik kriptografiyada shifrlash va deshifrlash uchun bir xil maxfiy kalitdan foydalaniladi. Ushbu yondashuv tezkor ishlashi va hisoblash resurslarini kam talab qilishi sababli zamonaviy axborot tizimlarida keng qo'llaniladi. Shu jihatdan simmetrik algoritmlarning nazariy va amaliy imkoniyatlarini o'rganish muhim ilmiy vazifa hisoblanadi.[2; 9-b.]

Simmetrik kriptografiya nazariyasi

Simmetrik kriptografiya - ma'lumotlarni himoyalashning eng qadimiy va samarali usullaridan biri bo'lib, unda shifrlash va deshifrlash jarayonlari yagona maxfiy kalit asosida amalga oshiriladi. Ushbu tizimning asosiy g'oyasi shundan iboratki, ma'lumot yuboruvchi va qabul qiluvchi oldindan bir xil kalitga ega bo'ladi.

Simmetrik tizimning umumiy ishlash mexanizmi quyidagicha ifodalanadi:

$$C = E_K(M)$$

bu yerda:

M – ochiq matn, K – maxfiy kalit, E – shifrlash funksiyasi, C – shifrlangan matn.

Deshifrlash jarayoni esa:

$$M = D_K(C)$$

ko'rinishida amalga oshiriladi.

Simmetrik algoritmlar ikki asosiy turga bo'linadi: blokli va oqimli algoritmlar. Blokli algoritmlar ma'lumotni ma'lum hajmdagi bloklarga bo'lib qayta ishlaydi, oqimli algoritmlar esa ma'lumotni bitlar oqimi sifatida shifrlaydi. Amaliyotda blokli algoritmlar yuqori xavfsizlik darajasi tufayli ko'proq qo'llaniladi.

Simmetrik shifrlashning asosiy afzalligi uning tezligidadir. Katta hajmdagi ma'lumotlar qisqa vaqt ichida shifrlanishi mumkin. Shu bilan birga, tizimning zaif tomoni kalitlarni xavfsiz almashish masalasi hisoblanadi. Agar maxfiy kalit uchinchi shaxs tomonidan qo'lga kiritilsa, ma'lumotlar himoyasi buziladi. Shu sababli zamonaviy tizimlarda simmetrik va assimetrik kriptografiya ko'pincha birgalikda qo'llanadi.[3; 67-b.]

Xulosa. Kiberxavfsizlik sohasida simmetrik shifrlash algoritmlari axborot xavfsizligini ta'minlashning muhim vositalaridan biri hisoblanadi. Raqamli texnologiyalar keng rivojlanayotgan sharoitda ma'lumotlarning maxfiyligi, yaxlitligi va ishonchliligini saqlash dolzarb masalaga aylanmoqda. Shu nuqtai nazardan, simmetrik kriptografiya yuqori tezlikda ishlashi, hisoblash resurslarini kam talab qilishi va katta hajmdagi ma'lumotlarni samarali himoya qilishi bilan alohida ahamiyat kasb etadi.

Tahlillar shuni ko'rsatadiki, DES algoritmi kriptografiya rivojlanishida muhim bosqich bo'lgan bo'lsa-da, bugungi hisoblash imkoniyatlari sharoitida uning himoya darajasi yetarli emas. AES esa murakkab matematik asosga ega bo'lib, 128, 192 va 256 bitli kalitlar yordamida yuqori kriptobardoshlikni ta'minlaydi. Blowfish va boshqa simmetrik algoritmlar ham ayrim tizimlarda samarali qo'llanilayotgan bo'lsa-da, zamonaviy axborot xavfsizligi standartlarida AES yetakchi o'rinni egallab kelmoqda.

Tezisdagi keltirilgan matematik model shifrlash jarayonining mantiqiy va algebraik asoslarini tushunishga yordam beradi. Xususan, chekli maydonlar algebraasi va XOR amallariga tayangan AES modeli ma'lumotlarni ko'p bosqichli transformatsiyalar orqali himoyalash imkonini beradi. Bu esa algoritmnining differensial va statistik hujumlarga nisbatan barqarorligini oshiradi.

Shuningdek, simmetrik shifrlash algoritmlarining bank tizimlari, elektron to'lov platformalari, VPN tarmoqlari, bulutli texnologiyalar hamda mobil kommunikatsiya vositalarida keng qo'llanilishi ularning amaliy ahamiyatini tasdiqlaydi. Biroq kalitlarni xavfsiz uzatish muammosi simmetrik kriptografiyaning dolzarb cheklolaridan biri bo'lib qolmoqda. Shu sababli kelgusida simmetrik va assimetrik usullarni integratsiyalash, shuningdek kvant texnologiyalari davriga mos kriptografik mexanizmlarni ishlab chiqish muhim ilmiy yo'nalishlardan biri bo'lib qoladi.

Shunday qilib, simmetrik shifrlash algoritmlari zamonaviy kiberxavfsizlik tizimlarining ajralmas tarkibiy qismi bo'lib, axborotlarni ishonchli himoya qilishda strategik ahamiyatga ega.

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SIMMETRIK SHIFRLASH ALGORITMLARINING NOCHIZIQLI KOMPONENTLARINI OPTIMAL TANLASH USULLARI VA BAHOLASH MEZONLARI

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Annotatsiya. Mazkur tezisdagi simmetrik shifrlash algoritmlarida qo'llaniladigan nochiziqli komponentlar, xususan S-bloklarning kriptografik ahamiyati, ularni optimal tanlash usullari hamda baholash mezonlari tahlil qilingan. Tadqiqot davomida zamonaviy ilmiy adabiyotlar asosida genetik algoritmlar, matematik modellar, xaotik tizimlar va evolyutsion yondashuvlar yordamida S-bloklarni yaratish usullari ko'rib chiqilgan. Shuningdek, nochiziqchilik, differensial bir xillik, SAC, bitlar mustaqilligi va Uolsh Adamar almashtirish kabi mezonlarning xavfsizlikka ta'siri tahlil etilgan. Olingan natijalar simmetrik kriptografiyada yuqori xavfsizlik darajasiga ega bo'lgan nochiziqli komponentlarni yaratishda kompleks baholash yondashuvlari muhim ekanligini ko'rsatadi.

Kalit so'zlar: simmetrik kriptografiya, S-blok, nochiziqchilik, differensial kriptotahlil, avalanche effekti, genetik algoritmi, xaotik tizimlar.

Kirish. Raqamli texnologiyalarning jadal rivojlanishi axborot xavfsizligi masalalarini yanada dolzarb qilib qo'yimoqda. Zamonaviy axborot tizimlarida ma'lumotlarni himoya qilishning asosiy vositalaridan biri kriptografik algoritmlar hisoblanadi. Simmetrik shifrlash algoritmlari yuqori tezkorlik va samaradorlikka ega bo'lgani sababli amaliyotda keng qo'llaniladi. AES, DES, Serpent, Blowfish va GOST kabi algoritmlar bank tizimlari, mobil aloqa, elektron hukumat va bulutli texnologiyalarda keng foydalaniladi.

Simmetrik shifrlash tizimlarining xavfsizligi ko'p jihatdan ularning nochiziqli komponentlariga bog'liq bo'ladi. Ayniqsa, S-bloklar algoritmnining asosiy xavfsizlik elementi sifatida muhim rol o'ynaydi. S-bloklar kirish ma'lumotlarini murakkab tarzda o'zgartirib, shifrlash jarayonida “confusion” xususiyatini hosil qiladi. Natijada ochiq matn bilan shifrlangan matn

orasidagi bog‘liqlikni aniqlash murakkablashadi. Kriptografik tizimlarning rivojlanishi bilan bir qatorda ularga qarshi hujum usullari ham takomillashib bormoqda.

Nochiziqli komponentlarning kriptografiyadagi ahamiyati. Shannon tomonidan ilgari surilgan “confusion” va “diffusion” tamoyillari zamonaviy kriptografiyaning asosini tashkil etadi. Simmetrik algoritmlarda diffusion odatda permutatsiya va aralashtirish jarayonlari orqali hosil qilinsa, confusion xususiyati aynan S-bloklar yordamida ta’minlanadi.

S-blok – bu kirish bitlarini chiqish bitlariga nochiziqli tarzda moslashtiruvchi jadval yoki matematik funksiyadir. AES algoritmda 8×8 o‘lchamdagi S-blok qo‘llaniladi va u chekli maydon arifmetikasi asosida qurilgan. DES algoritmda esa bir nechta 6×4 o‘lchamli S-bloklardan foydalanilgan.

Nochiziqli komponentlarni optimal tanlash usullari.

Genetik algoritmlar asosidagi yondashuv. Zamonaviy tadqiqotlarda genetik algoritmlar yordamida optimal S-bloklarni yaratish keng qo‘llanilmoqda. Ushbu yondashuv biologik evolyutsiya tamoyillariga asoslanadi. Dastlab tasodifiy S-bloklar generatsiya qilinadi, keyinchalik ular tanlash, mutatsiya va krossingover amallari orqali optimallashtiriladi. Kuznetsov va hammualliflari tomonidan olib borilgan tadqiqotlarda genetik algoritmlar yordamida yuqori nochiziqlilikka ega 8×8 o‘lchamdagi S-bloklar yaratilgan. Mualliflar Uolsh Adamar almashtirish funksiyasi asosida optimallashtirishni amalga oshirib, 104 darajadagi nochiziqlilikka erishganlar [1], [2].

Genetik algoritmlarning afzalligi – katta qidiruv fazosida optimal yechimlarni tez topish imkoniyatidir. Bundan tashqari, parallel hisoblash imkoniyati mavjudligi ushbu usul samaradorligini oshiradi.

Matematik modellar asosidagi usullar. Matematik modellar asosida S-blok yaratishda algebraik strukturalar, chekli maydonlar va modulyar arifmetikadan foydalaniladi. AES algoritmining S-bloki $GF(2^8)$ chekli maydonidagi teskari elementlarni affine transformatsiya orqali qayta ishlash asosida qurilgan.

Kashmar va boshqalar tomonidan taklif etilgan modelda kalitga bog‘liq matematik S-bloklar ishlab chiqilgan [3]. Bunday yondashuvning ustunligi shundaki, har bir sessiyada yangi S-blok hosil bo‘ladi va bu kriptotahlilni sezilarli darajada murakkablashtiradi.

Xaotik tizimlar asosidagi yondashuv. Xaos nazariyasi asosida yaratilgan S-bloklar yuqori tasodifiylik va murakkablikka ega bo‘ladi. Xaotik tizimlarning boshlang‘ich shartlarga juda sezgirliги kriptografiya uchun qulay xususiyat hisoblanadi.

Tolpa va hammualliflari tomonidan taklif etilgan xaosga asoslangan yengil S-blok modeli IoT qurilmalari uchun samarali yechim sifatida tavsiya etilgan [4]. Tadqiqot natijalariga ko‘ra, ushbu model yuqori avalanche effektiga va differensial bardoshlilikka ega.

Gibrid maydon va o‘rin almashtirish usullari asosida S-bloklar yaratish ham istiqbolli yo‘nalishlardan biridir. Hussain va boshqalar tomonidan ishlab chiqilgan modelda S_8 guruh permutatsiyasi asosida yangi S-bloklar generatsiya qilingan [5]. Mazkur yondashuv yordamida yaratilgan S-bloklar bijektivlik, differensial uniformlik va bit mustaqilligi mezonlari bo‘yicha yuqori natijalarni ko‘rsatgan.

Nochiziqli komponentlarni baholash mezonlari

Nochiziqlilik mezon. Nochiziqlilik S-blokning chiziqli funksiyalardan uzoqlik darajasini ifodalaydi. Ushbu ko‘rsatkich qanchalik katta bo‘lsa, algoritmi chiziqli kriptotahlilga shunchalik bardoshli bo‘ladi.

AES algoritmi S-bloki yuqori nochiziqlilikka ega bo‘lib, bu uning xavfsizlik darajasini oshiradi [8].

Differensial kriptotahlilga bardoshlilik. Differensial kriptotahlil kirishdagi kichik o‘zgarishlarning chiqishga qanday ta’sir qilishini baholaydi. Past differensial bir xillik differensial kriptotahlilga qarshi kuchli himoya beradi. DES va Serpent algoritmlarida aynan ushbu mezon asosiy loyihalash talabi sifatida qo‘llangan.

Qa’tiy lavin samaradorlik bo‘yicha kirishdagi bitta bit o‘zgarishi chiqish bitlarining taxminan yarmiga ta’sir qilishi kerak. Kuchli lavin samaradorlik ma’lumotlarning statistik

bog'liqligini kamaytiradi. Hussain va hammualliflari ishlab chiqqan S-bloklarda mazkur mezon muvaffaqiyatli bajarilgani ko'rsatilgan [5].

Bitlar mustaqilligi mezon chiqish bitlarining o'zaro bog'liq emasligini baholaydi. Ushbu mezon statistik hujumlarga bardoshlilikni oshirishda muhim hisoblanadi. NIST yengil kriptografiya ustida olib borilgan tadqiqotlarda BIC mezon asosiy indikatorlardan biri sifatida qo'llangan [6].

Uolsh Adamar almashtirish S-blokning chiziqli funksiyalar bilan korrelyatsiyasini aniqlaydi. Ushbu mezon orqali nochiziqlilik darajasi hisoblanadi.

Kuznetsov va boshqalar aynan ushbu spektr asosida optimal S-bloklarni yaratishga muvaffaq bo'lganlar [1].

Xulosa

Tahlil qilingan ilmiy adabiyotlar simmetrik shifrlash algoritmlarida nochiziqli komponentlar hal qiluvchi ahamiyatga ega ekanligini ko'rsatdi. S-bloklar algoritmning differensial va chiziqli kriptotahlilga bardoshlilikni ta'minlovchi asosiy element hisoblanadi.

Optimal S-bloklarni yaratishda genetik algoritmlar, matematik modellar, xaotik tizimlar va evolyutsion usullar samarali natijalar bermoqda. Zamonaviy tadqiqotlarda ayniqsa yuqori nochiziqlilik, past differensial uniformlik va kuchli avalanche effektiga ega komponentlarni yaratishga katta e'tibor qaratilmoqda.

Baholash mezonlari sifatida nochiziqlilik, differensial bardoshlilik, bit mustaqilligi va Walsh–Hadamard spektri eng muhim indikatorlar hisoblanadi. Kelajakda sun'iy intellekt va post-kvant kriptografiya asosidagi yangi avlod nochiziqli komponentlarini yaratish ushbu yo'nalishning asosiy ilmiy vazifalaridan biri bo'lib qoladi.

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OBYEKT LARNING SHAXSIY ALOMATLAR FAZOSINI QURISH ASOSIDA GETEROGEN INTELLEKTUAL TIZIMLAR QARORLARINI TUSHUNTIRISH

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Annotatsiya

Maqolada geterogen intellektual tizimlarda qarorlarni tushuntirishning yangi yondashuvi sifatida obyektlarning shaxsiy alomatlar fazosini qurish masalasi ko'rib chiqilgan. Tadqiqotda tushuntiruvchi sun'iy intellekt konsepsiyasi doirasida har bir obyekt uchun uning sinfiga eng xarakterli bo'lgan individual alomatlarni aniqlashga asoslangan algoritm taklif etilgan. Yondashuv tegishlilik funksiyalari va regularizatsiya mexanizmlaridan foydalanish orqali obyektlarning informativ tavsiflarini shakllantirish hamda miqdoriy va nominal alomatlarni yagona fazoda unifikatsiya qilish imkonini beradi. Maqolada mavjud lokal interpretatsiya usullari va shaxsiy alomatlar fazosini qurish yondashuvlari qiyosiy tahlil qilinib, taklif etilgan algoritmning afzalliklari asoslab berilgan. Tadqiqot natijalari tibbiyot, psixologiya va bioinformatika kabi murakkab predmet

sohalarida interpretatsiyalanadigan informatsion modellarni yaratishda ushbu yondashuvning istiqbolliligini ko'rsatadi.

Kirish. Tushuntiruvchi sun'iy intellekt (Explainable Artificial Intelligence, XAI) sun'iy intellekt va berilganlarni tahlil qilishning eng jadal rivojlanayotgan yo'nalishlaridan biri bo'lib, tibbiyot, iqtisodiyot, xavfsizlik va boshqa sohalarida intellektual tizimlar qabul qilgan qarorlarni izohlashga yo'naltirilgan [1, 2].

XAI ilmiy yo'nalish sifatida mashinali o'rgatish, statistika va sabab-oqibat tahlili sohalaridagi bir qator fundamental hamda amaliy tadqiqotlar asosida shakllangan. Jumladan, modellarni lokal interpretatsiya qilish bo'yicha olib borilgan tadqiqotlar muhim hissa qo'shgan. Xususan, Marco Tulio Ribeiro va hammualliflarining 2016-yildagi maqolasida murakkab modellarni interpretatsiyalanadigan lokal tasvirlar orqali approksimatsiya qilish imkonini beruvchi LIME usuli taklif etilgan [3]. Chuqur neyron to'rlarni interpretatsiya qilish sohasida esa Grad-CAM kabi vizualizatsiya usullari muhim o'rin egallab, ular model qaroriga kuchli ta'sir ko'rsatuvchi kirish berilganlar to'plam ostilarini aniqlash imkonini beradi [4].

Zamonaviy XAI usullarining samaradorligiga qaramay, ularning aksariyati an'anaviy mashinali o'rgatish modellarini interpretatsiya qilishga yo'naltirilgan. Shu bilan birga, tanlanma obyektlari darajasida tushuntirishga bag'ishlangan tadqiqotlar hajmi nisbatan kamdir. Istiqbolli yo'nalishlardan biri obyektning lokal qonuniyatlariga asoslangan holda uning shaxsiy alomatlar fazosini shakllantirish hisoblanadi.

Obyektning shaxsiy alomatlar fazosi g'oyasi har bir obyekt uchun uning ma'lum bir sinfga tegishliligini eng to'liq tavsiflovchi individual alomatlar to'plami mavjud degan farazga asoslanadi. Bunday yondashuv obyektlar o'rtasidagi o'zaro bog'liqliklar murakkab tuzilishga ega bo'lgan predmet sohalarida, jumladan tibbiyot, psixologiya va bioinformatikada ayniqsa dolzarbdir.

Masalaning matematik qo'yilishi. Obyektlarning $E_0 = \{S_1, \dots, S_m\}$ tanlanmasi berilgan bo'lib, uning har bir obyekt $X(n) = (x_1, \dots, x_n)$ nominal alomatlar vektori bilan tavsiflangan. Tanlanma o'zaro kesishmaydigan ikkita K_1 va K_2 sinfga ajratilgan. $S \in E_0$ obyektining K_1 va K_2 sinflardan biriga tegishliligini hisobga olgan holda uning shaxsiy alomatlar fazosini qurish algoritmini ishlab chiqish talab etiladi.

Algoritm:

Tanlanma obyekt tavsifidagi $x_i \in X(n)$ alomatning har bir unikal qiymatiga $\{1, \dots, \mu_i\}$ to'plamidan mos sonlarni qo'yiladi, bu yerda $\mu_i - x_i$ alomatining unikal qiymatlari (gradatsiyalar) soni.

1. Alomatning μ gradatsiyasi bo'yicha tegishlilik funksiyasi qiymati hisoblansin:

$$f_{ij}(\mu) = \frac{\frac{d_{ji}(\mu)}{|K_j|}}{\frac{d_{ji}(\mu)}{|K_j|} + \frac{d_{3-ji}(\mu)}{|K_{3-j}|}},$$

bu yerda $d_{ji}(\mu)$ va $d_{3-ji}(\mu)$ – mos ravishda K_j va K_{3-j} sinflardagi μ gradatsiya qiymatiga ega obyektlar soni.

2. Har bir $S \in K_j$ ($S = (a_1, \dots, a_n)$) uchun $\Delta(S) = \{i | f_{ij}(a_i) > 0.5\}$ hisoblansin.

3. x_i alomat S obyekt shaxsiy alomatlar fazosiga kiradi, agar $x_i \in \Delta(S)$ va

$$\frac{(f_{ij}(a_i) - 0.5)}{P_i} > \lambda, \quad 0.5 < \lambda < 1,$$

bu yerda $P_i = \max \left(\min_{f_{ij}(\mu) > 0.5} f_{ij}(\mu) - \max_{f_{ij}(\mu) < 0.5} f_{ij}(\mu) \right)$.

4. Berilgan $S \in E_0$ uchun regulyatorning $\lambda = 0.6$ qiymati uchun shaxsiy alomatlar fazosi aniqlansin.

Obyektning shaxsiy alomatlar fazosini qurish yondashuvlarining qiyosiy tahlili. Shaxsiy alomatlar fazosi masofa metrikalari, sinflar qobiqlari va obyektlar orasidagi munosabatlarga asoslangan obyektlar bog'liqligining binar fazosi sifatida shakllantirish [5] ishda qaralgan. Ushbu yondashuv global xarakterga ega bo'lib, tanlanmaning umumiy tuzilishini hisobga

oladi. Asosiy vazifalar sifatida sinflarning kompaktligini baholash, o‘zaro bog‘langan obyektlar guruhlarini ajratish, etalon obyektlarni aniqlash hamda shovqin obyektlarni o‘chirish amalga oshiriladi.

Mazkur g‘oyaning rivojlantirilgan ko‘rinishi [6] ishda keltirilgan bo‘lib, unda shaxsiy alomatlar fazosini qurish lokal yaqinlik metrikalari, sinflar kompaktligi mezonlari va latent alomatlar asosida amalga oshiriladi. Ishda miqdoriy hamda nominal alomatlardan foydalanilgan, shuningdek yangi latent alomatlarini shakllantirish uchun aglomerativ guruhlash qoidasi qo‘llangan. Bunday yondashuv alomatlar orasidagi yashirin bog‘liqliklarni hisobga olish hamda informativ tavsiflarni izlashdagi kombinator murakkablikni kamaytirish imkonini beradi.

Yuqorida keltirilgan yondashuvlar asosan tanlanmaning geometrik tuzilishi va lokal metrikalariga, sinflarning kompaktligiga hamda latent alomatlar sinteziga yo‘naltirilgan.

Taklif etilayotgan algoritm esa turli tipdagi alomatlarini (miqdoriy va nominal) unifikatsiya qilish hamda kompakt va informativ tasvirni shakllantirish uchun tegishlilik funksiyalaridan foydalanishga qaratilgan. Obyektning shaxsiy alomatlar fazosi uning sinfiga eng xarakterli bo‘lgan individual alomatlar to‘plami sifatida shakllantiriladi.

Xulosa. Obyektning shaxsiy alomatlar fazosini qurish XAI rivojlantirishning istiqbolli yo‘nalishlaridan biri hisoblanadi. Global interpretatsiya usullaridan farqli ravishda, ushbu yondashuv obyektlarning individual xususiyatlariga yo‘naltirilgan bo‘lib, lokal izohlanuvchi modellarni shakllantirish imkonini beradi.

Taklif etilgan yondashuv sinfga tegishlilik funksiyalari va regulyarizatsiya asosida obyektning informativ alomatlarini ajratib ko‘rsatishni ta‘minlaydi. Yondashuvning amaliy ahamiyati murakkab predmet sohalarida, avvalo tibbiyot, psixologiya va bioinformatikada interpretatsiyalanadigan informatsion modellarni qurish imkoniyati bilan belgilanadi.

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ПОСТРОЕНИЕ МОДЕЛИ СУГЕНО ДЛЯ РЕШЕНИЯ ЗАДАЧ ДИАГНОСТИКИ РАКА ГРУДИ

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Аннотация. В данной работе исследуется применение нечеткой логической модели Сугено для решения задачи диагностики, основанной на медицинских данных. Задача диагностики является ключевой в медицинской практике, особенно в области раннего

выявления заболеваний, таких как рак. В данной работе модель Сугено адаптируется для решения задачи диагностики рака молочной железы на основе характеристик клеток. Для построения модели проводится предварительная обработка и анализ данных, включая нормализацию и отбор признаков. Затем определяются нечеткие правила на основе экспертных знаний или анализа данных.

Ключевые слова: нечеткая логика, модель Сугено, диагностика, классификация, медицинские приложения, обработка неопределенности, точность классификации.

Диагностика заболеваний является одной из ключевых областей медицины, где применение современных методов машинного обучения и искусственного интеллекта может принести значительные выгоды. В частности, задача раннего выявления рака, включая рак молочной железы, имеет большое значение для эффективного лечения и выживаемости пациентов. Несмотря на значительные усилия в области медицинских исследований, точность и скорость диагностики рака остаются актуальными проблемами. В связи с этим активно исследуются новые подходы, включая использование методов машинного обучения для автоматизации процесса диагностики на основе медицинских данных. Целью данной работы является исследование эффективности нечеткой логической модели Мамдани и модели Сугено в контексте задачи диагностики рака молочной железы на основе медицинских данных. Будут рассмотрены методы построения моделей, их обучение и оценка с использованием различных метрик качества классификации [1].

Основной целью данного исследования является разработка и оценка эффективности нечеткой логической модели Сугено для задачи ранней диагностики рака груди на основе медицинских данных. Цель работы заключается в создании интерпретируемой и надёжной интеллектуальной системы, способной повысить точность классификации образцов клеток и поддержать врачей при принятии диагностических решений.

В рамках данного исследования основными задачами являются разработка и адаптация нечеткой логической модели для диагностики рака груди и оценка её эффективности на основе медицинских данных. Для этого предусматривается проведение анализа исходной информации, её нормализация и выделение наиболее значимых признаков, формирование базы нечетких правил на основе экспертных знаний и статистических характеристик, обучение модели и её оценка с использованием стандартных метрик классификации, таких как точность, полнота и F1-мера.

Для построения и оценки моделей используется набор данных о раке молочной железы, доступный в библиотеке scikit-learn. Этот набор данных содержит информацию о различных признаках, таких как радиус, текстура и размер опухоли, а также метки классов, указывающие на то, является ли опухоль злокачественной или доброкачественной. Для решения задачи классификации используются нечеткие логические модели, включая модель Сугено. Эти модели основаны на принципах нечеткой логики и позволяют моделировать нечеткое или неопределенное знание. Перед применением моделей данные проходят процесс предобработки, включающий в себя шаги нормализации, масштабирования и возможно отбора признаков. Модели Сугено обучаются на обучающем наборе данных с использованием методов обучения с учителем, таких как метод опорных векторов или метод ближайших соседей. В процессе обучения модели настраивают свои параметры таким образом, чтобы минимизировать выбранную функцию потерь. Для оценки качества построенных моделей используются различные метрики, такие как точность, полнота, F1-мера и матрица путаницы. Кроме того, может использоваться кросс-валидация для более объективной оценки моделей. После построения и оценки нескольких моделей проводится их сравнение с целью выбора наилучшей модели для решения конкретной задачи диагностики рака молочной железы. Этапы моделирования включают в себя подготовку данных, выбор моделей, их обучение и оценку, что позволяет определить наиболее эффективный подход к решению задачи диагностики [3].

В начале рассмотрим применение фильтра Калмана для идентификации на основе нечеткой базы знаний Сугено. Задачу нечеткой идентификации будем рассматривать как

нахождение таких коэффициентов в заключениях правил, которые обеспечивают минимальное отклонения между данными наблюдений и результатами логического вывода по нечеткой базе знаний Сугено.

Предполагаются, что известны:

1) выборка экспериментальных данных (X_r, y_r) , $r = \overline{1, M}$, где

$X_r = (x_{r,1}, x_{r,2}, \dots, x_{r,n})$ - входной вектор в r -ой паре и y_r - соответствующий выход;

2) правила нечеткой базы знаний Такаги-Сугено:

$$\bigcup_{p=1}^{k_j} \left(\bigcap_{i=1}^n x_i = a_{i,jp} \right) \longrightarrow y = b_{j,0} + b_{j,1} \cdot x_1 + b_{j,2} \cdot x_2 + \dots + b_{j,n} \cdot x_n, j = \overline{1, m}$$

Необходимо найти такие значения коэффициентов заключений правил

$B = (b_{1,0}, b_{2,0}, \dots, b_{m,0}, b_{1,1}, b_{2,1}, \dots, b_{1,n}, b_{2,n}, \dots, b_{m,n})^T$, которые обеспечивают минимум квадратичной невязки:

$$\sum_{r=1, M} (y_r - y_r^f)^2 \longrightarrow \min, \quad (1)$$

где y_r^f - результат вывода по нечеткой базе знаний с параметрами **B** при значении входов из r -й строчки выборки (X_r) .

Входному вектору $X_r = (x_{r,1}, x_{r,2}, \dots, x_{r,n})$ соответствует такой результат нечеткого вывода:

$$y_r^f = \frac{\sum_{j=1, m} \mu_{d_j}(X_r) \cdot d_j}{\sum_{j=1, m} \mu_{d_j}(X_r)} \quad (2)$$

где $d_j = b_{j,0} + \sum_{i=1, n} b_{j,i} \cdot x_{r,i}$ - заключение j -го правила;

$\mu_{d_j}(X_r) = \bigvee_{p=1, k_j} w_{jp} \cdot \bigwedge_{i=1, n} \left[\mu_{jp}(x_{r,i}) \right]$ - степень выполнения заключения j -го правила.

Обозначим через $\beta_{j,r} = \frac{\mu_{d_j}(X_r)}{\sum_{k=1, m} \mu_{d_k}(X_r)}$ относительную степень выполнения заключения

j -го правила для входного вектора X_r . Тогда (2) можно переписать в виде:

$$y_r^f = \sum_{j=1, m} (\beta_{r,j} \cdot b_{j,0} + \beta_{r,j} \cdot b_{j,1} \cdot x_{r,1} + \beta_{r,j} \cdot b_{j,2} \cdot x_{r,2} + \dots + \beta_{r,j} \cdot b_{j,n} \cdot x_{r,n})$$

Введем следующие обозначения:

$$Y^f = (y_1^f, y_2^f, \dots, y_M^f)^T,$$

$$Y = (y_1, y_2, \dots, y_M)^T;$$

$$A = \begin{bmatrix} \beta_{1,1}, \dots, \beta_{1,m}, & x_{1,1} \cdot \beta_{1,1}, \dots, x_{1,1} \cdot \beta_{1,m}, & x_{1,n} \cdot \beta_{1,1}, \dots, x_{1,n} \cdot \beta_{1,m} \\ \vdots & \vdots & \vdots \\ \beta_{M,1}, \dots, \beta_{M,m}, & x_{M,1} \cdot \beta_{1,1}, \dots, x_{M,1} \cdot \beta_{1,m}, & x_{M,n} \cdot \beta_{M,1}, \dots, x_{M,n} \cdot \beta_{M,m} \end{bmatrix}.$$

Тогда задача (1) в матричной форме ставится следующим образом: найти вектор **B**, чтобы:

$$E = (Y - Y^f)^T \cdot (Y - Y^f) \longrightarrow \min, \quad (3)$$

где $Y^f = A \cdot B$.

Минимальное значение квадратичной невязки E достигается при $Y^f = Y$, что соответствует решению уравнения

$$Y = A \cdot B. \quad (4)$$

Для реальных задач количество настраиваемых параметров меньше объема выборки данных $m \cdot (n+1) < M$, поэтому уравнение (4) не имеет точного решения. В этом случае решение можно найти, используя псевдоинверсию матрицы A :

$$B = (A^T \cdot A)^{-1} \cdot A^T \cdot Y. \quad (5)$$

Результаты данного исследования показали, что модель на основе нечеткой логики Сугено имеет потенциал для применения в задачах диагностики. Общая точность классификации составила 91.23%, что свидетельствует о хорошей способности модели предсказывать правильные диагнозы. Однако для дальнейшего улучшения производительности и надежности модели могут потребоваться дополнительные исследования и оптимизации. Использование нечеткой логики позволяет модели учитывать неопределенность и размытость входных данных, что особенно важно в медицинских приложениях, где данные могут быть неточными или неоднозначными. Однако необходимо учитывать, что данная модель требует аккуратного подбора параметров и тщательного обучения для достижения оптимальных результатов. Таким образом, нечеткая логика Сугено представляет собой мощный инструмент для решения задач диагностики, и ее применение может привести к улучшению процесса принятия решений в медицинской практике.

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SAVOL-JAVOB TIZIMLARINI YARATISHDA KO'P AGENTLI RAG (AGENTIC RAG) TIZIMLARINI QO'LLASH

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Annotatsiya—Ushbu maqolada call-markazlari faoliyatini avtomatlashtirish uchun ilg'or ko'p agentli Retrieval-Augmented Generation (Agentic RAG) tizimlarining arxitekturasini va ularning savol-javob tizimlarini ishlab chiqishda qo'llanilishi keltirilgan. An'anaviy RAG tizimlari murakkab, gibril va relyatsion so'rovlarni qayta ishlashda cheklangan imkoniyatlarga ega ekanligi sababli, rejalashtiruvchi (Planner), qadam belgilovchi (Step Definer), filtrlovchi (Extractor) va tanqid qiluvchi (Critic) modullardan iborat ko'p agentli kontseptsiyasidan foydalanish taklif etilgan. Tizim o'zbek tilidagi qonunchilik hujjatlari va davlat xizmatlari ma'lumotlar bazalari (relyatsion ma'lumotlar) o'rtasida integratsiyani ta'minlash uchun Model Context Protocol (MCP) interfeysidan foydalanadi. Tadqiqot doirasida gibril qidiruv modellari, Markov qaror qabul qilish jarayonlariga (MDP) asoslangan agentli boshqaruv va probabilistik javob generatsiyasi

mexanizmlari batafsil bayon etilgan. Taklif etilgan arxitektura call-markazlardagi robotlashtirilgan ovoqli yordamchilarning faktologik aniqligini oshirish, gallyutsinatsiyalarni minimallashtirish va murakkab ko'p qadamlı savollarga to'g'ri javob berishini kafolatlaydi.

Kalit so'zlar—*Agentic RAG, Ko'p agentli tizimlar, MA-RAG, HYBGRAG, Davlat xizmatlari markazi, Model Context Protocol, O'zbek tili NLP, Hybrid Retrieval, BM25, ModernUzBERT.*

Zamonaviy raqamli texnologiyalar rivojlanagan jamiyatda davlat boshqaruvi va fuqarolarga xizmat ko'rsatish tizimini raqamlashtirish davlat siyosatining ustuvor yo'nalishlaridan biri hisoblanadi. O'zbekiston Respublikasida Yagona interaktiv davlat xizmatlari portali (my.gov.uz) va hudulardagi Davlat xizmatlari markazlari (DXM) orqali yuzlab turdagi xizmatlar ko'rsatib kelinmoqda. Biroq, ko'rsatilayotgan xizmatlar ko'lamining kengayishi call-markazlarga kelib tushayotgan so'rovlar sonining keskin ortishiga olib keldi. Fuqarolar tomonidan beriladigan savollar faqatgina oddiy axborot xarakteriga ega bo'lmay, ko'pincha murakkab normativ-huquqiy tartibga solish mexanizmlarini, turli idoralararo bazalardan ma'lumotlarni tekshirishni va ketma-ket bir necha bosqichli mantiqiy xulosalarni talab qiladi.

So'nggi yillarda Katta til modellari (Large Language Models — LLM) matn yaratish va savollarga javob berish sohasida ulkan muvaffaqiyatlarga erishdi. Biroq, davlat xizmatlari kabi yuqori mas'uliyatli va huquqiy aniqlik talab etiladigan sohalarda LLMlarni to'g'ridan-to'g'ri qo'llash jiddiy xavflarni yuzaga keltiradi. Birinchidan, ushbu modellar o'zining ichki bilimlariga tayanib javob berganda faktlarni buzib ko'rsatish yoki mavjud bo'lmagan qoidalarni to'qib chiqarish (gallyutsinatsiya) tendentsiyasiga ega. Ikkinchidan, qonunchilik va reglamentlar muntazam ravishda o'zgarib turadi, LLMlarni har safar qayta o'qitish (fine-tuning) esa juda katta hisoblash resurslari va vaqt talab qiladi.

Ushbu muammoni hal qilish maqsadida ma'lumotlarni tashqi manbadan qidirib topish va generatsiyani boyitish (Retrieval-Augmented Generation — RAG) texnologiyasi joriy etildi. RAG tizimi foydalanuvchi savoliga mos keladigan normativ hujjatlarni tashqi bazadan izlab topadi va ularni kontekst sifatida LLMga uzatadi, bu esa gallyutsinatsiyalarni sezilarli darajada kamaytiradi. Biroq, an'anaviy RAG tizimlari davlat xizmatlaridagi gibrid muammolarni hal qila olmaydi. Masalan, fuqaroning: "Yangi haydovchilik guvohnomasini olish uchun qanday hujjatlar kerak va mening arizam tayyor bo'ldimi?" degan savoli gibrid xarakterga ega. Bu erda savolning birinchi qismi matnli ma'lumotlar bazasidan (reglament hujjati) qidirishni, ikkinchi qismi esa relyatsion ma'lumotlar bazasidan (arizalar holati jadvali yoki API) ma'lumot olishni talab etadi.

Ushbu muammoni hal etish uchun mazkur tadqiqotda ko'p agentli hamkorlikka asoslangan Agentic RAG arxitekturasi taklif etiladi. Mazkur tizim murakkab savollarni quyi vazifalarga bo'luvchi Rejalashtiruvchi (Planner), tegishli vositalarni tanlovchi Yo'naltiruvchi (Router), relyatsion va matnli qidiruvni amalga oshiruvchi hamda olingan natijalarni kritik tahlil qiluvchi agentlar tarmog'idan tashkil topadi. Tizim o'zbek tilining morfologik va sintaktik xususiyatlarini hisobga olgan holda gibrid va relyatsion bilimlar bazalari ustida yuqori aniqlikda ishlashga moslashtirilgan.

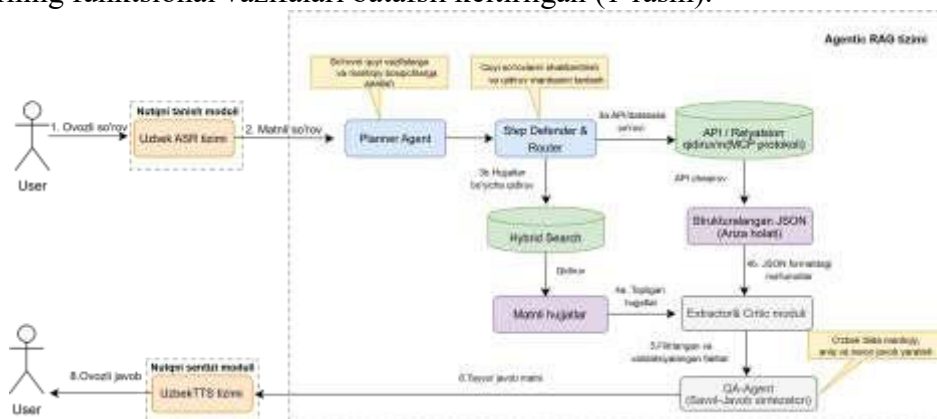
RAG sohasidagi so'nggi fundamental tadqiqotlar shuni ko'rsatadiki, an'anaviy bir bosqichli qidiruv va generatsiya zanjiri mantiqiy va gibrid so'rovlar oldida ojizdir. Murakkab axborot qidirish vazifalarini hal qilishda bir nechta ixtisoslashgan agentlarning hamkorligi va o'z-o'zini tahlil qilish (self-reflection) mexanizmlari eng samarali yechim sifatida namoyon bo'lmoqda[.]

Davlat xizmatlari markazlari qoshidagi call-markazlari kontekstida muammoning qo'yilishi quyidagicha ifodalanadi: Berilgan foydalanuvchi so'rovi q asosida qonunchilik hujjatlari to'plami D va relyatsion ma'lumotlar bazasi (yoki API xizmatlari) G dan shunday X ma'lumotlar to'plamini ajratib olish kerakki, u ham matnli reglament talablariga muvofiq bo'lsin, ham fuqaroning shaxsiy arizasi holatiga to'g'ri kelsin, so'ngra olingan natija asosida o'zbek tilida aniq y muloqot javobi sintez qilinishi lozim.

Ko'p agentli Agentic RAG arxitekturasi

Davlat xizmatlari avtomatlashtirilgan ovoqli va matnli robot interfeysi tarkibida taklif etilayotgan ko'p agentli Agentic RAG tizimi bir-biri bilan cheklangan muloqot interfeyslari orqali

bog‘langan mustaqil komponentlardan iborat. Tizim foydalanuvchining ovozi xabarini qabul qilgandan so‘ng, uni o‘zbek tili oqimli nutqni tanish tizimi modeli yordamida matnga o‘giradi. Ushbu matn ko‘p agentli RAG tizimiga kirish parametri sifatida uzatiladi. Quyida tizimning asosiy agentlari va ularning funksional vazifalari batafsil keltirilgan (1-rasm).



1-rasm. Ko‘p agentli Agentic RAG arxitekturası

1. *Rejalashtiruvchi Agent (Planner Agent)*. Planner Agent foydalanuvchining birlamchi q so‘rovini qabul qilib, uning murakkablik darajasi va semantik tarkibini tahlil qiladi. Agar savol ko‘p mantiqiy bosqichlardan iborat bo‘lsa, u savolni o‘zaro kesishmaydigan quyi vazifalar to‘plamiga ajratadi: $P = \{s_1, s_2, \dots, s_n\}$. Har bir s_i qadam mantiqiy ketma-ketlikda joylashtiriladi va keyingi agentlar uchun ko‘rsatma vazifasini bajaradi. Rejalashtiruvchi bir marta ishga tushirilib, yuqori darajadagi strategik rejani shakllantiradi.

2. *Qadam Belgilovchi va yo‘naltiruvchi Agent (Step Definer & Router)*. Ushbu agent joriy s_i qadamning maqsadini, asl q savolni va shu vaqtgacha to‘plangan tarixiy muloqot kontekstini (H_{i-1}) inobatga olgan holda batafsil quyi so‘rov shakllantiradi. So‘ngra yo‘naltiruvchi mexanizmi ishga tushadi. Agar quyi so‘rov normativ qoidalarni aniqlashga qaratilgan bo‘lsa, u matnli qidiruv modulini tanlaydi. Arizaning holati, shaxsiy ma‘lumotlar yoki to‘lov statusini tekshirish lozim bo‘lsa, tizim relyatsion qidiruv modulini (Relational/API Module) faollashtiradi.

Relyatsion tizimlar va tashqi APIlar bilan xavfsiz va standartlashtirilgan aloqa o‘rnatish uchun tizimda Model Context Protocol (MCP) integratsiya qilingan. MCP orqali til modeli my.gov.uz backend xizmatlariga to‘g‘ridan-to‘g‘ri xavfsiz JSON so‘rovlar yuborish imkoniyatiga ega bo‘ladi.

3. *Filtrlovchi va tanqidchi modul (Extractor & Critic Module)*. Qidiruv modullaridan olingan ma‘lumotlar odatda ortiqcha elementlar va shovqinlarga ega bo‘ladi. Extractor Agent olingan hujjatlar yoki API natijalari ichidan faqatgina joriy so‘rovga tegishli faktlarni (gaplar yoki kalit qiymatlarni) ajratib oladi va ixchamlashtiradi. Bu jarayon yirik kontekst o‘rtasida kerakli ma‘lumotning yo‘qolib qolishi muammosini oldini oladi.

Tanqidchi modul tarkibidagi validator olingan ma‘lumotlarning foydalanuvchi talabiga mosligini ikkilik klassifikatsiya orqali tekshiradi. Agar ma‘lumot yetarsiz yoki noto‘g‘ri deb topilsa, Commenter moduli ishga tushib, Router uchun maxsus tuzatuvchi teskari aloqa) tayyorlaydi va qidiruv qaytadan mantiqiy tuzatishlar bilan amalga oshiriladi (Self-Reflection mexanizmi).

4. *Savol-Javob Agenti (QA Agent/Synthesizer)*. Barcha quyi qadamlar muvaffaqiyatli yakunlanib, validator tomonidan tasdiqlanganidan so‘ng, QA agent barcha filtrlangan faktlarni jamlaydi. U kontekstli ta‘lim (In-Context Learning — ICL) namunalari asosida fuqaro uchun o‘zbek tilida rasmiy-muloqot uslubida, ixcham va faktologik jihatdan 100% aniq yakuniy javob matnini sintez qiladi. Ushbu matn o‘zbek tili nutq sintezatori VITS modeli orqali ovozlashtirilib, foydalanuvchiga taqdim etiladi.

Gibrid Axborot Qidiruv Modeli (Hybrid Retrieval Model)

O‘zbek tilidagi normativ-huquqiy hujjatlar bazasidan D qidirishda ham semantik o‘xshashlikni, ham kalit so‘zlarning aniq mosligini ta‘minlash maqsadida zich (dense) va siyrak (sparse) qidiruv baholarining chiziqli kombinatsiyasidan foydalaniladi. Foydalanuvchi so‘rovi q va hujjat d o‘rtasidagi gibrid relevanlik reytingi $S(q, d)$ quyidagi tenglama orqali hisoblanadi:

$$S(q, d) = \alpha \cdot S_{dense}(q, d) + (1 - \alpha) \cdot S_{sparse}(q, d)$$

Bu yerda: $\alpha \in [0,1]$ — zich va siyrak qidiruv modellarining vaznini belgilovchi balanslashtirish koeffitsienti. $S_{dense}(q, d)$ — Embedding modeli yordamida olingan vektorli ko‘rinishlarning kosinusli o‘xshashlik darajasi bo‘lib, u quyidagicha aniqlanadi:

$$S_{dense}(q, d) = [E(q) \cdot E(d)] / [\|E(q)\| \cdot \|E(d)\|]$$

$S_{sparse}(q, d)$ esa terminlarning chastotaviy o‘xshashligini hisoblovchi BM25 algoritmining reyting qiymatidir. U o‘zbek tilidagi qo‘shimchalar (masalan, -ni, -ning, -da) olib tashlangan o‘zak so‘zlar (lemmatizatsiya) ustida quyidagi formula asosida hisoblanadi[].

$$S_{sparse}(q, d) = \sum_{q \in q} IDF(q) \cdot \frac{f(q, d) \cdot (k_1 + 1)}{f(q, d) + k_1 \cdot (1 - b + b \cdot \frac{|d|}{avgdl})},$$

Ko‘p qadamli rejalashtirishning Markov qaror jarayoni (Markov Decision Process — MDP)

Ko‘p agentli tizimda rejalashtirish va qidiruvni boshqarish Markov qaror qabul qilish jarayoni sifatida modellashtiriladi. MDP modeli (S, A, P, R) to‘plami orqali aniqlanadi, bu yerda:

1. S — holatlar fazosi. t -qadamdagi s_t holati o‘z ichiga asl q so‘rovni va shu vaqtgacha bajarilgan quyi vazifalar va olingan javoblar tarixini H_t oladi.

2. A — harakatlar fazosi. Har bir a_t harakati router tomonidan aniqlanadigan aniq quyi so‘rov shakli va murojaat qilinadigan vositani (MCP API yoki matnli qidiruv) anglatadi.

3. $P(s_{t+1} | s_t, a_t)$ — o‘tish ehtimolligi. Bu modul qidiruv natijalarining validator tomonidan qabul qilinishi yoki rad etilishiga ko‘ra keyingi holatga o‘tishni belgilaydi.

4. $R(s_t, a_t)$ — mukofot funksiyasi. Validator tomonidan javobning to‘g‘riligi tasdiqlansa, tizim musbat mukofot ($R=1$) oladi va jarayon to‘xtaydi, aks holda manfiy mukofot beriladi.

Agentning maqsadli boshqaruv siyosati $\pi_\phi(a_t | s_t)$ til modelining prompt muhandisligi va kontekstli misollar orqali optimallashtiriladi, bu esa minimal qadamlar sonida to‘g‘ri ma‘lumotlar to‘plamiga erishishni ta‘minlaydi.

Probabilistik javob generatsiyasi

QA agent tomonidan yakuniy y javob matnini sintez qilish jarayoni shartli ehtimolliklar ko‘paytmasi ko‘rinishida ifodalanadi. Bunda generatsiya faqatgina q so‘rovga emas, balki Extractor tomonidan filtrlangan va tasdiqlangan $C_{extracted}$ kontekstiga qat‘iy bog‘lanadi.

$$P(y|q, C_{extracted}) = \prod_{t=1}^N P(y_t | y_{<t}, q, C_{extracted}; \theta)$$

Bu yerda θ — qo‘llanilayotgan yirik til modelining vazn parametrlari hisoblanadi. Ehtimollikning ushbu ko‘rinishda cheklanishi modelning o‘z ichki xotirasidan noto‘g‘ri ma‘lumotlarni aralashtirish ehtimolini nolgacha tushiradi.

Ushbu tadqiqot doirasida Davlat xizmatlari markazlari call-markazlari faoliyatini takomillashtirish va avtomatlashtirishga qaratilgan ko‘p agentli Agentic RAG arxitekturasini va uning mantiqiy-matematik asosi ishlab chiqildi. Tizim murakkab va gibril so‘rovlarni muvaffaqiyatli parchalash, matnli reglamentlar va relyatsion ma‘lumotlar bazalaridan (MCP orqali) qidiruvni amalga oshirish hamda natijalarni ko‘p bosqichli kritik tahlildan o‘tkazish qobiliyatiga ega.

Kelajakdagi tadqiqot yo‘nalishlari ko‘p agentli muloqot zanjirining kechikish vaqtini yanada qisqartirish, o‘zbek tili uchun kabi zich vektorli modellarni DXM terminologiyasi asosida chuqurroq fine-tuning qilish hamda nutqni tanish va sintez qilish modullari bilan apparat darajasidagi integratsiyani optimallashtirishga qaratiladi.

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PREPROCESS AND ANALYZE KEYBOARD DYNAMICS DATA

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Abstract: This article develops a software system designed for the collection, storage, mathematical modeling, and preliminary analysis of time indicators generated during the user's keyboard input process. The program is based on the Flask web framework and the SQLite database and records user key down and key up events. Based on these phenomena, it is possible to calculate keyboard dynamics features such as dwell time, flight time, PP, RR, PR, RP. For each recording attempt, a feature vector is generated that represents the user's individual recording style. The program serves to generate experimental data for the further development of user identification and authentication algorithms based on keyboard dynamics.

Keywords: Keyboard dynamics, mathematical model, dwell time, flight time, key down, key up, biometric authentication, feature vector, user profile, Flask, SQLite.

Introduction. Currently, one of the pressing issues in information systems is the reliable identification of a user, monitoring their activity in the system, and preventing unauthorized access. Traditional login and password-based authentication methods often fail to provide sufficient security. Passwords can be forgotten, leaked, or compromised. Therefore, there is a growing need for biometric approaches aimed at identifying a user based on their personal behavior [1].

Keyboard dynamics is one of the biometric methods based on studying the individual time characteristics of the user during the typing process. This method analyzes user attributes such as key press and release time, key transition interval, typing speed, error rate, and editing habits. Keyboard dynamics is a non-invasive, low-cost, and device-free method that allows you to learn the user's typing style using a simple keyboard. Even in scientific literature, keystroke dynamics is presented as a convenient, low-cost, and remotely applicable biometric method for user verification [2,3].

There are many studies on user identification and authentication in the field of keyboard dynamics. However, for the effective development of such systems, it is first necessary to accurately record the user's recording process, correctly distinguish time indicators, and analyze them based on a mathematical model. Existing scientific works show that it is difficult to directly compare the results of various studies in keyboard dynamics systems. This is because the number of users, password length, text type, keyboard type, feature set, and evaluation criteria vary in research. Therefore, at the initial stage, it is important to develop a unified data collection mechanism, a precise mathematical model, and a stable set of features [4].

The program developed in this study is aimed at solving this problem. The program records the user's text input process in real time, saves keydown and keyup events, and calculates dwell time, flight time, and other timestamps based on them. As a result, a vector of features is generated that mathematically describes the user's writing style [5,6].

The relevance of the problem is determined by the following:

- 1) in addition to the password, it is possible to verify the user's behavior using additional characteristics;
- 2) special experimental data is generated for keyboard dynamics;
- 3) the ability to analyze factors such as the user's hand position, device type, keyboard type, and writing environment;
- 4) in the future, a ready-made database of properties for machine learning algorithms will be created.

Research methodology. The research methodology is aimed at collecting phenomena that arise during the user's text input process via the keyboard, expressing them based on a mathematical model, and performing preliminary analysis. In the study, each user is considered as a separate object:

$$\mathcal{U} = \{u_1, u_2, \dots, u_n\} \#(1)$$

Each user u_i is described by attributes such as gender, age, age group, and sex predisposition. During the experiment, various types of text samples are provided to the user. The set of texts is defined as follows:

$$\mathcal{T} = \{t_1, t_2, \dots, t_m\} \#(2)$$

each text sample t_j consists of a title, type, and content. Each user typing process is recorded as a separate session. The user typing session is described in the form of a multidimensional vector consisting of eight interconnected contextual attributes: user identifier, input mode, typing ergonomics (state), technical device type, keyboard configuration, web browser, operating system, and keyboard distribution (language location). The study considers the cases of normal positioning, right-hand, left-hand, one-handed, and two-handed typing.

During typing, each key press and release is recorded as a separate event:

$$\mathcal{E} = \{e_1, e_2, \dots, e_r\} \#(3)$$

Here, the e_i -input event is a set of four pieces of information: the key code, the key value, the type of event, and the time it occurred. The press time of each button is denoted by D_i , and the release time by U_i . The dwell time is calculated based on these values:

$$H_i = U_i - D_i$$

The time relationships between consecutive keys are defined as follows:

$$PP_i = D_{i+1} - D_i \quad RR_i = U_{i+1} - U_i \quad PR_i = U_i - D_i \quad RP_i = D_{i+1} - U_i$$

Where PP , RR , PR , RP are the main keyboard dynamics symbols representing the user's typing rhythm. Flight time is formed based on RP_i -values. At the next stage, the statistical indicators of the allocated timestamps are calculated. Determine the mean, standard deviation, and median values for the dwell time and flight time. Also, the total recording time is determined as follows:

$$T_{total} = t_{max} - t_{min}$$

The entered text is compared with the sample text and the number of errors is calculated. If sample text is A and user input is B

$$Error = |n - m| + \sum_{i=1}^{\min(n,m)} I(a_i \neq b_i) \#(4)$$

where $I(a_i \neq b_i)$ is an indicator function that identifies incompatible features.

After each recording attempt, a vector of features is generated that describes the user's recording style:

$$X_i = [\bar{H}, \sigma_H, Med_H, \bar{F}, \sigma_F, Med_F, T_{total}, Error, B_s, R_s]$$

Here B_s - is the number of times the Backspace key is used, and R_s - is the number of times attempts are restarted.

A shared keyboard profile is created based on multiple attempts by the same user:

$$P_u = \frac{1}{p} \sum_{i=1}^p X_i \#(5)$$

This profile mathematically represents the user's individual writing style. In the future, a new recording sample may be matched to the user profile and an authentication decision may be made using Euclidean distance [7]. Thus, the research methodology consists of the stages of collecting keyboard events, extracting time characteristics, statistical processing, forming a feature vector, and creating a user profile. This approach provides a scientific basis for developing user identification and authentication algorithms based on keyboard dynamics [8]. The developed program allowed for the recording of the user's text input process via the keyboard and its preliminary analysis. During typing, the keydown and keyup events of each key are stored, and timestamps representing the user's typing style are calculated based on them [9].

The analysis results show that dwell time characterizes the duration of the user's button press, while flight time characterizes the speed of transition between buttons. The number of errors, Backspace, and Restart serve to assess the user's stability in typing and editing habits. The presence of a separate experimental mode for hand positioning in the program allows for the comparison of the user's normal, right-handed, left-handed, one-handed, and two-handed typing positions [10]. This allows for the determination of changes in keyboard dynamics under various recording conditions.

Conclusion. In this study, a software system was developed for collecting, storing, and preliminary analyzing the user's typing characteristics based on keyboard dynamics. The program allows for the recording of user keydown and keyup events and the calculation of important timestamps based on them, such as dwell time, flight time, PP, RR, PR, and RP. The developed system performs the task of collecting and preliminary processing the data necessary for forming a user profile based on keyboard dynamics. In the future, these feature vectors can be used for user identification or authentication, as well as for applying machine learning algorithms.

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TIMSOLLARNI TANIB OLISH MASALALARIDA OBYEKTAR MUHIMLIGINI ANIQLASHNING AXBOROT O'LCHOVI MEZONLARI

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Annotatsiya. Mazkur ma'ruzada timsollarni tanib olish masalalarida obyektlar muhimligini axborot o'lchovi mezonlari asosida baholashning nazariy va amaliy jihatlari tadqiq etilgan. Tadqiqotda obyektlarning informativligi, o'ziga xosligi, aniqligi, muvofiqligi hamda kontekstga mosligi kabi ko'rsatkichlarning tanib olish tizimlari samaradorligiga ta'siri tahlil qilingan. Axborot nazariyasiga asoslangan entropiya, o'zaro axborot (Mutual Information), aniqlik darajasi (Precision), eslab qolish (Recall), F1 bahosi va IoU kabi mezonlarning matematik mohiyati hamda ularning obyektlarni tasniflash jarayonidagi ahamiyati yoritilgan. Shuningdek, Convolutional Neural Network (CNN) algoritmlarining tasvirlarni qayta ishlash va obyektlarni tanib olishdagi imkoniyatlari ko'rib chiqilgan. Tadqiqot natijalari axborot o'lchovi mezonlaridan foydalanish tanib olish tizimlarining aniqligi, ishonchliligi va samaradorligini oshirishda muhim omil ekanligini ko'rsatdi. Mazkur yondashuv tibbiy diagnostika, kompyuter ko'rishi va intellektual tahlil tizimlarida samarali qo'llanishi mumkin.

Kalit so'zlar: tanib olish obyektlari, obyektlar muhimligi, axborot o'lchovi, entropiya, kompyuter ko'rishi, CNN (Convolutional Neural Network), mashinaviy o'qitish, o'zaro axborot, o'ziga xoslik, aniqlik, ma'lumotlarni qayta ishlash, sun'iy intellekt.

I. Kirish

Zamonaviy axborot texnologiyalari, sun'iy intellekt va mashinaviy o'qitish usullarining jadal rivojlanishi natijasida timsollarni tanib olish tizimlari turli ilmiy va amaliy sohalarda keng qo'llanilmoqda. Xususan, xavfsizlik, tibbiyot, sanoat, transport hamda biometrik identifikatsiya tizimlarida obyektlarni avtomatik aniqlash va tasniflash masalalari muhim ilmiy-amaliy ahamiyat kasb etmoqda. Ushbu jarayonlarda kompyuter ko'rishi (Computer Vision) va mashinaviy o'qitish (Machine Learning) algoritmlari asosiy texnologik vosita sifatida qo'llanilib, ayniqsa Convolutional Neural Network (CNN) modellari yuqori aniqlikdagi natijalarni ta'minlamoqda.

Obyektlarni tanib olish tizimlarining samaradorligi ko'p jihatdan ma'lumotlarning informativligi va obyekt belgilarining muhimlik darajasiga bog'liq hisoblanadi. Yuqori o'lchamli belgilar fazosida informativ bo'lmagan parametrlar tasniflash aniqligini pasaytirishi hamda hisoblash murakkabligini oshirishi mumkin. Shu sababli axborot o'lchovi mezonlari asosida obyektlarning o'ziga xosligi, aniqligi, to'liqligi, muvofiqligi va kontekstga mosligini baholash dolzarb ilmiy masalalardan biri hisoblanadi. Ayniqsa, tibbiy tasvirlarni tahlil qilish jarayonida obyektlar muhimligini aniqlash diagnostika aniqligini oshirish va kasalliklarni erta aniqlashda muhim ahamiyat kasb etadi. Axborot nazariyasiga asoslangan entropiya, o'zaro axborot (Mutual Information), aniqlik darajasi (Precision), eslab qolish (Recall), F1 bahosi hamda IoU kabi mezonlar obyektlarning informativlik darajasini miqdoriy baholash imkonini beradi. Mazkur mezonlar yordamida tanib olish tizimlarida obyektlarning ahamiyat darajasini aniqlash, model samaradorligini oshirish va noaniqlikni kamaytirish mumkin.

Mazkur tadqiqot ishida timsollarni tanib olish masalalarida obyektlar muhimligini axborot o'lchovi mezonlari asosida baholash usullari hamda ularni hisoblash algoritmlarining nazariy va amaliy jihatlari tahlil qilinadi.

II. Assosiy qism

Tanib olish obyektlarining muhimligini axborot o'lchovi mezonlari asosida baholash obyekt bilan bog'liq ma'lumotlarning informativligi, aniqligi va tizim uchun foydalilik darajasini aniqlashni anglatadi. Obyektlarning axborot mazmunini baholash mezonlari qo'llanilish sohasi va masalaning xususiyatiga qarab farqlanishi mumkin. Bunda obyektning o'ziga xosligi, muhimligi, muvofiqligi, aniqligi, to'liqligi, barqarorligi, samaradorligi, kontekstga mosligi, xavfsizligi, masshtablilik hamda moslashuvchanligi asosiy ko'rsatkichlar sifatida qaraladi. Ayniqsa, tibbiy timsollarni tanib olish masalalarida informativ belgilarni aniqlash va ularning muhimlik darajasini baholash diagnostika aniqligini oshirishda muhim ahamiyat kasb etadi [1–5].

Tanib olish tizimlarida obyektlarning o'ziga xosligi ularni boshqa obyektlardan ajratib turuvchi individual belgilar orqali aniqlanadi. Masalan, yuzni tanib olish tizimlarida ko'z, burun va yuz shakli kabi parametrlar shaxslarni identifikatsiyalash uchun muhim informativ belgilar hisoblanadi. Shuningdek, avtomobillarni aniqlash tizimlarida transport vositasining rangi, turi va

davlat raqami asosiy identifikatsiya parametrlari sifatida qo'llaniladi. Smart-kuzatuv tizimlarida esa tasvir, ovoz va harakat sensorlari yordamida inson, hayvon yoki boshqa obyektlarni aniqlash amalga oshiriladi. Matnlarni qayta ishlash tizimlarida esa algoritmlar so'z va belgilarni tahlil qilish hamda ularni semantik kategoriyalarga ajratish imkonini beradi.

Obyektlarni tanib olish masalalarini hal etishda kompyuter ko'rishi (Computer Vision) va mashinaviy o'qitish (Machine Learning) texnologiyalaridan keng foydalaniladi. Xususan, Convolutional Neural Network (CNN) algoritmlari tasvirlarni qayta ishlash va obyektlarni aniqlashda yuqori samaradorlikka ega bo'lgan chuqur o'qitish modellaridan biri hisoblanadi. CNN arxitekturasida kiruvchi tasvirlar o'ramali qatlamlar orqali qayta ishlanib, filtrlash jarayonida muhim belgilar ajratib olinadi. Keyingi pooling qatlamlarida ma'lumotlar o'lchami qisqartirilib, hisoblash murakkabligi kamaytiriladi. Yakuniy bosqichda esa to'liq bog'lanishli qatlamlar orqali obyektlarni tasniflash yoki regressiya masalalari bajariladi. Ushbu yondashuv tasvirlardan informativ belgilarni avtomatik ajratib olish va sinflashtirish aniqligini oshirish imkonini beradi.

Tanib olish obyektlarining axborot mazmunini axborot nazariyasidan tushunchalar yordamida miqdoriy aniqlash mumkin. Obyektni tanib olishda ma'lumot ko'pincha modelning tasvirlar ichidagi obyektlarni to'g'ri aniqlay olishi aniqligi bilan o'lchanadi. Biroq, o'lchash ma'lumotlari ko'p qirrali bo'lishi mumkin va aniqlik, eslab qolish, F1 balli va boshqalar kabi aniq nimani baholashga bog'liq.

Mana, ularning matematik ifodalari va bir nechta turli mezonlar [6–8]:

1. Aniqlik. Aniqlik barcha misollar orasida to'g'ri aniqlangan holatlar ulushini o'lchaydi. U quyidagicha hisoblanadi:

$$\text{Aniqlik} = \frac{\text{To'g'ri bashoratlar soni}}{\text{Bashoratlarning umumiy soni}}$$

2. Aniqlik. Aniqlik - barcha ijobiy identifikatsiyalar (haqiqiy ijobiy va noto'g'ri musbatlar) orasidagi haqiqiy ijobiy identifikatsiyalar nisbati. U quyidagicha hisoblanadi:

$$\text{Aniqlik} = \frac{\text{Haqiqiy ijobiy tomonlar}}{\text{Haqiqiy ijobiy tomonlar} + \text{Soxta pozitivlar}}$$

3. Yeslab qolish (sezuvchanlik). Yeslab qolish - barcha haqiqiy ijobiy holatlar (haqiqiy ijobiy va noto'g'ri salbiy) o'rtasidagi haqiqiy ijobiy identifikatsiyalarning nisbati. U quyidagicha hisoblanadi:

$$\text{Eslab qolish} = \frac{\text{Haqiqiy ijobiy tomonlar}}{\text{Haqiqiy ijobiy tomonlar} + \text{noto'g'ri salbiy}}$$

4. F1 ball. F1 balli aniqlik va eslab qolishning garmonik o'rtacha ko'rsatkichidir va ikkalasi o'rtasidagi muvozanatni ta'minlaydi. U quyidagicha hisoblanadi:

$$F1 \text{ ball} = 2 \cdot \frac{\text{Aniqlik} + \text{Esga olish}}{\text{Aniqlik} + \text{Esga olish}}$$

5. Kesishma yig'indi asosida (IoU). IoU - odatda, obyektni tanib olishda umumiy kesishma va asosiy yig'indi obyektlarini o'rtasidagi o'xshashlikni o'lchash uchun ishlatiladi. U quyidagicha hisoblanadi:

$$\text{IoU} = \frac{\text{kesishmasi}}{\text{yig'indisi}}$$

6. Entropiya. Axborot nazariyasida entropiya noaniqlik yoki tartibsizlik miqdorining o'lchovidir. Obyektni tanib olish uchun u obyektlarni tasniflashda noaniqlikni ifodalashi mumkin. U quyidagicha hisoblanadi:

$$H(X) = - \sum_{i=1}^n p(x_i) \log_2 p(x_i)$$

Bu yerda $p(x_i)$ hodisa ehtimoli, x_i kuzatilayotgan obyekt.

7. O'zaro ma'lumot. O'zaro ma'lumot obyektni tanib olish kontekstida kuzatilgan obyekt va haqiqiy obyekt yorlig'i o'rtasida boshqa tasodifiy o'zgaruvchi orqali bitta tasodifiy o'zgaruvchi haqida olingan ma'lumotlar miqdorini aniqlaydi:

$$I(X; Y) = \sum_{y \in Y} \sum_{x \in X} p(x, y) \log\left(\frac{p(x, y)}{p(x)p(y)}\right)$$

Bu yerda X va Y - mos ravishda kuzatilayotgan obyekt va haqiqiy obyektlarni ifodalovchi tasodifiy o'zgaruvchilar, $p(x, y)$ esa birgalikdagi.

Obyektlarni tanib olishda ma'lumotni o'lchash uchun ushbu ko'rsatkichlarning biri yoki kombinatsiyasi ishlatilishi mumkin.

III. Xulosa

Mazkur tadqiqot ishida timsollarni tanib olish tizimlarida obyektlar muhimligini axborot o'lchovi mezonlari asosida baholashning nazariy va amaliy jihatlari tahlil qilindi. Tadqiqot natijalari obyektlarning informativligini aniqlash tanib olish tizimlarining aniqligi, ishonchligi va samaradorligini oshirishda muhim omil ekanligini ko'rsatdi. Xususan, entropiya, o'zaro axborot (Mutual Information), aniqlik (Precision), eslab qolish (Recall), F1 bahosi va IoU kabi mezonlar obyektlarni tasniflash sifatini baholashda samarali ko'rsatkichlar sifatida qo'llanilishi aniqlandi. Shuningdek, Convolutional Neural Network (CNN) algoritmlarining tasvirlarni qayta ishlash va obyektlarni tanib olish jarayonidagi samaradorligi tahlil qilindi. CNN modellari yordamida informativ belgilarni ajratib olish va obyektlarni yuqori aniqlikda tasniflash imkoniyati mavjudligi asoslandi. Tadqiqot davomida axborot o'lchovi mezonlarini tanib olish algoritmlariga integratsiyalash model samaradorligini oshirish hamda hisoblash jarayonlarini optimallashtirishga xizmat qilishi ko'rsatildi. Bunda ko'rinadiki, olingan natijalar tibbiy diagnostika, kompyuter ko'rishi, biometrik identifikatsiya va intellektual tahlil tizimlarida obyektlarni tanib olish sifatini oshirishda amaliy ahamiyatga ega hisoblanadi.

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HAYDOVCHILARNI KUZATISH TIZIMLARIDA TESHIKLI KAMERA MODEL VA GEOMETRIK KALIBRLASH

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Annotatsiya: Haydovchilarni avtomobil boshqarishda kuzatish tizimlari (DMS) haydovchilarning charchoqlari va chalg'ituvchi omillarini real vaqt rejimida aniqlash orqali yo'l harakati xavfsizligini oshirishda muhim rol o'ynaydi. Ushbu maqolada pinhole kamera modeli va geometrik kalibrlash texnikasining bunday tizimlarning asosiy matematikasi sifatida keng qamrovli tahlili keltirilgan. Kameraning ichki va tashqi parametrlari shakllantirilgan va tasvirni shakllantirish jarayoni proyektiv geometriya yordamida tasvirlangan. Monokulyar chuqurlikning noaniqligi va linzalarning buzilishi kabi asosiy muammolar, shuningdek, kalibrlash va baholash algoritmlari yordamida ularni hal qilish usullari ko'rib chiqilgan.

Kalit so'zlar: Haydovchini kuzatish; Kamerani kalibrlash; Pinhole modeli; Chuqurlikni baholash; Boshning holati; Multimodal termoyadroviy

Haydovchilarning charchog'i va chalg'ishi butun dunyo bo'ylab yo'l-transport hodisalarining asosiy sabablaridan biridir. Zamonaviy haydovchilarni kuzatish tizimlari (DMS) bunday holatlarni kompyuter ko'rish va sun'iy intellekt texnikalari yordamida aniqlashga qaratilgan. Ushbu tizimlarning aniqligi tasvir shakllanishi va fazoviy munosabatlarning aniq geometrik modellashga bog'liq. Pinhole kamera modeli uch o'lchovli (3D) dunyo koordinatalarini ikki o'lchovli (2D) tasvir koordinatalariga xaritalash uchun asosiy matematik asos bo'lib xizmat qiladi. Ushbu model tasvirlash jarayonining soddalashtirilgan, ammo kuchli tasvirini taqdim etadi va haydovchilarni kuzatish dasturlarida keyingi hisoblashlar uchun asos bo'lib xizmat qiladi. Pinhole kamera modeli haydovchi monitoring tizimida amalga oshirilgan barcha vizualizatsiya jarayonlari uchun fundamental geometrik asosni ta'minlash. Ushbu ideallashtirilgan model kamerani cheksiz kichik o'lchamga ega bo'lgan yagona nuqta - optik markaz sifatida qaraydi. Ushbu markaz orqali o'tuvchi yorug'lik nurlari uch o'lchamli (3D) fazodagi obyektlarni ikki o'lchamli (2D) tekisligiga proyeksiya qiladi. Modeling soddaligi tasvir hosil bo'lish jarayonini aniq matematik ifodalash imkonini beradi va fizik o'lchovlarni raqamli tasvir koordinatalariga o'tkazishda muhim rol o'ynaydi. Pinhole kamera modeli tasvir hosil bo'lish jarayonini to'liq tavsiflash uchun bir nechta koordinata tizimlari ajratiladi. Bunda **3D dunyo koordinata tizimi** (World Coordinate System) obyektlarning fazodagi haqiqiy joylashuvini ifodalaydi. Ikkinchidan, **kamera** koordinata tizimi (Camera Coordinate System) optik markazga qarab undan Z o'qi optik o'q bo'ylab yo'nalgan bo'ladi. Uchinchidan, **tasvir** koordinata tizimi (Image Coordinate System) - bu uzluksiz 2D tekislik bo'lib, unda proyeksiyalangan nuqtalar joylashadi. **Piksel** koordinata tizimi (Pixel Coordinate System) tasvir tekisligini diskret ko'rinishga keltirib, uni sensor panjarasi asosida ifodalaydi. Ushbu koordinata tizimlari o'zaro transformatsiyalar orqali bog'lanadi va bu transformatsiyalar tasvirni ishlash jarayonida muhim ahamiyatga ega. Tasvir 3D fazodagi nuqtaning 2D tasvir tekisligiga proyeksiyasi pinhole modeling asosiy tenglamasi bilan ifodalanadi. Ush tenglama nuqtaning chuqurlik koordinatasiz orqali masshtablashni o'rgangan holda tasvir koordinatasi aniqlaydi.

Pinhole modeling muhimligi shundaki - bu uning matematik texnologiyasi soddaligi bilan birga, real tizimlarda yuqori aniqlik bilan qo'llab-quvvatlanadi. Fizik jihatdan pinhole kamera modeli tasvir hosil bo'lishining nazariy asosini, balki haydovchi monitoring qilish tizimlarida real vaqt rejimida fazoviy amalga oshirish uchun zarur bo'lgan geometrik infratuzilmani ham taluqli bolishi lozim. Pinhole kamera modeli 3D nuqtaning 2D tasvir tekisligiga proektsiyasini tasvirlaydi. Matematik formula quyidagicha berilgan:

$$x = f \frac{X}{Z}, y = f \frac{Y}{Z}, \quad (1)$$

X,Y,Z- fazo koordinatalari, f-fokus masofalari, (x,y)-tasvir tekisligidagi koordinatalar. Bu qulay kamera obyektga tasvirlangan yaqin bo'lsa, o'lchami shunchalik katta bo'ladi, uzoqlashgan sari esa kichrayadi. Amaliy tizimlarda tasvir uzluksiz tekislikda emas, balki diskret piksel panjarasida ifodalanadi. Shu yuqoridagi tenglamalar piksellar koordinatalarga o'xshash. Bunda kamera ichki matritsasi yordamida yordam dasturi:

$$z = \alpha \frac{X}{Z} + c_x, \quad v = \beta \frac{Y}{Z} + c_y \quad (2)$$

Bu yerda α , β - piksel o'lchamiga moslangan focus masofalar, c_x , c_y tasvir markazidagi nuqta, z , v piksel kordinatalari.

Mazkur model yanada umumiy korinishda ifodalash uchun gomogen koordinatalardan foydalaniladi. Bu holda proyeksiya jarayoni chiziqli algebra vositalari orqali quyidagicha yoziladi:

$$p = K[R/t]P, \quad (3)$$

K -kameraning ichki parametrlar matritsasi, R, t - kamera tashqi parametrlarini ifodalovchi aylana matritsasi va siljish vektori, P - 3D nuqta, p - 2D tasvir nuqtasi. Bu formula Real tizimlarda geometrik transformatsiyalarni samarali hisoblash imkonini beradi va kompyuter ko'rish algoritmlarining asosiy qismi hisoblanadi. Piphole modelining muhim jihatlaridan biri shundaki, tasvir hosil bo'lish jarayonini soddalashtirilgan holda, fazoviy ma'lumotlarni aniqlash uchun yetarli darajada aniqlikni ta'minlaydi. Shu sababli u haydovchini monitoring tizimlari, robototexnika, avtonom, transport va kengaytirilgan reallik kabi sohalarda keng qo'llaniladi. Ushbu modelning asosiy cheklovi - bu chuqurlik noaniqligi hisoblanadi. 2D nuqta kamera nur yo'li boylab joylashgan cheksiz kop 3D nuqtalariga mos kelishi mumkin. Bu fazoviy kordinatalarni to'liq tiklashni qiyinlashtiradi.

Real vaqt rejimida ishlovchi haydovchi monitoring tizimlarida tasvirdan olinadigan natijalar ko'pincha shovqinli, notekis va beqaror bo'lishi mumkin. Buning asosiy sabablari qatoriga kamera sensoridagi tasodifiy xatoliklar, yorug'lik sharoitining o'zgarishi, yuz landmarklarini aniqlashdagi kichik og'ishlar, boshning tez harakati, shuningdek, tasvirni qayta ishlash algoritmlarining kadrlar bo'yicha turlicha reaksiyasi kiradi. Natijada ketma-ket kadrlar orasida o'lchangan parametrlar, masalan, bosh holati burchaklari, chuqurlik qiymati yoki yuz landmarklarining kordinatalari keskin o'zgarib turishi mumkin. Bu esa tizimning umumiy barqarorligini pasaytiradi va noto'g'ri qarorlar qabul qilinishiga sabab bo'ladi. Temporal smoothing usullarining asosiy vazifasi - ketma-ket kadrlar orasidagi tasodifiy tebranishlarni kamaytirish, foydali signalni ajratib olish va vaqt bo'yicha izchil, fizik ma'noga ega natijalarni shakllantirishdan iborat. Bunday yondashuv, ayniqsa, haydovchi monitoring tizimlarida muhim, chunki haydovchining bosh holati, qarash yo'nalishi yoki charchoq belgilari bir zumda emas, balki ma'lum vaqt oralig'ida asta-sekin shakllanadi. Shuning uchun kadrma-kadr o'zgarishlarni emas, balki vaqt bo'yicha tahlil qilingan, barqaror parametrlarni kuzatish maqsadga muvofiqdir. Ushbu algoritm oddiy eksponensial silliqlash usulining takomillashtirilgan ko'rinishi bo'lib, u nafaqat joriy qiymatning umumiy tendensiyasini, balki o'zgarish tezligini ham hisobga oladi. Agar qiymatlardagi o'zgarish tasodifiy shovqin natijasi bo'lsa, algoritm uni bostiradi. Aksincha, agar o'zgarish ketma-ket bir necha kadr davomida kuzatilsa va u real harakat yoki holat o'zgarishini anglatasa, algoritm ushbu tendensiyaning saqlab qoladi. Shu sababli ADES usuli haydovchi boshining tabiiy burilishlari, ko'zning yumilishi yoki yuz holatidagi o'zgarishlarni aniqroq kuzatishga imkon beradi. Matematik jihatdan ikki martalik eksponensial silliqlash quyidagi umumiy ko'rinishda ifodalanadi:

$$\begin{aligned} S_t &= \alpha X_t + (1 - \alpha)(S_{t-1} + T_{t-1}) \\ T_t &= \beta(S_t - S_{t-1}) + (1 - \beta)T_{t-1} \end{aligned} \quad (4)$$

Bu yerda: X_t — vaqtning t -onidagi kuzatilgan qiymat, S_t — silliqlangan daraja qiymati, T_t — trend komponenti, α va β — silliqlash koeffitsientlari.

Adaptive shaklda esa α va β - parametrlar signalning variatsiyasi, shovqin darajasi yoki kadrlar orasidagi farqqa qarab dinamik ravishda tanlanadi. Bu esa algoritmni statik silliqlash usullariga nisbatan ancha moslashuvchan va samarali qiladi.

Haydovchi monitoring tizimlarida ADES algoritmi bir nechta muhim afzalliklarga ega. Birinchidan, u shovqinni kamaytiradi. Kamera va yuz landmark detektorlaridan olingan qiymatlar odatda mayda tebranishlarga ega bo'ladi. Bosh holati burchagi bir xil turgan bo'lsa ham, algoritm kadrlar bo'yicha kichik farqli qiymatlar qaytarishi mumkin. ADES ushbu mayda tebranishlarni

bostirib, tizimga yanada silliq signal beradi. Real vaqt tizimida foydalanuvchiga yoki qaror qabul qilish moduliga uzatiladigan parametrlar muntazam va izchil bo'lishi zarur. Agar har bir kadrda qiymatlar keskin sakrab tursa, tizim noto'g'ri ravishda haydovchi diqqatini yo'qotgan yoki boshini burayotgan deb baholashi mumkin. ADES esa kadrlar ketma-ketligida fizik jihatdan mantiqiy bo'lgan silliq o'tishni ta'minlaydi. Murakkab filtrlar, masalan, ba'zi ehtimollik yoki optimallashtirishga asoslangan usullar ko'p hisoblash resurslarini talab qilishi mumkin. Monokulyar kamera tizimlarida chuqurlik qiymatlari tabiatan noturg'un bo'lishi mumkin, chunki bitta tasvir asosida masofani aniq aniqlash qiyin. PnP orqali topilgan translatsiya komponentlari yoki landmarklar asosidagi masofa baholari kadrlar bo'yicha tebranishga ega bo'lishi mumkin. ADES ana shu qiymatlarni vaqt bo'yicha silliqlab, chuqurlikning fizik ma'noga ega, izchil bahosini ta'minlaydi. Kamera kalibrlash va pinhole modeli yordamida 2D tasvir koordinatalari bilan 3D fazoviy malumotlar o'rtasida aniq matematik bog'liqliklarni organadi. Bundan tashqari, taklif qilingan qism monokulyar kameralar uchun xos bo'lganlik noaniqligi muammosinian hal qilish imkonini beradi. PnP algoritmi va vaqt bo'yicha xatoliklarni bartaraf etish usullarini qo'llash orqali chuqurlikdagi komponenti barqarorroq baholanadi hamda qulayliklar kamaytiriladi. 3D fazoviy talqinda ancha aniq va muhim ma'lumotlarni taqdim etadi. Yondashuvning yana bir muhim afzalligi - uning real vaqt rejimida boshqarishdir.

Xulosa qilib aytganda geometrik modellashtirish va kamera kalibrlash haydovchi holatini ishonchli monitoring qilish tizimlarining muhim asosini tashkil qiladi. Pinhole kamera, mustahkam kalibrlash va chuqurlikni boshqarish usullarini birlashtirish orqali haydovchining bosh holati, qarash yo'nalishi va yuz orientatsiyasini aniq tahlil qilish mumkin. Bunday uyquchanlik, charchoq va diqqat susayishi real vaqt rejimida ishlashi tizimning ishonchligini orttiradi. Kelajakda tizimlarni real rejimda optimallashtirish, edge-qurilmalarda qo'lash va keng ko'lamli tajriba sinovlaridan o'tkazishni boshqarish vaqtini ta'minlashda muhim ilmiy-amaliy yo'nalish bo'lib xizmat qiladi.

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TANIB OLISH MASALALARIDA AXBOROT O'LCHOV MEZONLARIGA ASOSLANGAN INFORMATIV BELGILAR MAJMUASINI TANLASH ALGORITMI

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Annotatsiya: Mazkur ma'ruzada obyektlarning muhimligini baholash uchun axborot o'lchov mezonlariga asoslangan holda ishlab chiqilgan algoritm tavsifi bayon etilgan. Mazkur algoritm obyektlarni o'xshashlik darajasini aniqlash orqali informativ belgilar majmuasini tanlash masalasini yechishga e'tibor qaratilgan. Tadqiqot jarayonida obyektlarning o'xshashlik koeffitsiyenti va muhim axborot ko'rsatkichlari asosida sinf obyektlari orasidagi farqlar tahlil qilinib, ma'lumotlar hajmi optimallashtirilgan. Mazkur yondashuv mashinali o'qitish, timsollarni tanib olish va ma'lumotlarni intellektual qayta ishlash tizimlarida obyektlarning axborot muhimligini formal baholash, informativ belgilar fazosini shakllantirish hamda sinflashtirish jarayonida qaror qabul qilish aniqligi va hisoblash samaradorligini oshirishga xizmat qiluvchi samarali matematik-algoritmik yondashuv sifatida taklif etilgan.

Kalit so'zlar: axborot o'lchovi, obyektning tanib olish, o'xshashlik koeffitsiyenti, informativ belgilar, sinf obyekti, mashinali o'qitish, ma'lumotlar tahlili.

I. Kirish

Bugungi kunda axborot texnologiyalarining tez sur'atlarda rivojlanishi bilan obyektlarni tanib olish va ularni tasniflash masalalari ko'plab sohalarda muhim o'rin egallab kelmoqda. Xavfsizlik tizimlaridan tortib, tibbiy diagnostika, sanoat avtomatlashtirish va sun'iy intellektga asoslangan ko'plab jarayonlarda obyektlarni tanib olish sifatiga bog'liq bo'lib qolmoqda. Ayniqsa, katta hajmdagi ma'lumotlar bilan ishlashda, obyektlarning muhim belgilarini aniqlash va ular o'rasidagi o'zaro yashirin qonuniyatlarini aniqlash asosida samarali qarorlar qabul qilishga bo'lgan ehtiyoj ortib bormoqda [1-4].

Obyektlar muhimligini baholash uchun axborot o'lchov mezonlaridan foydalanish bunday tizimlarning samaradorligini oshirishda muhim ahamiyat kasb etadi. Axborot o'lchovlari obyektlar o'rtasidagi o'xshashlik darajalarini aniqlash uchun ishlab chiqilgan matematik mezonlar va algoritmlar hamda bu mezonlar obyektlarning asosiy xususiyatlari va informativ belgilarini aniqlashda yordam beradi. Tadqiqotda axborot o'lchov mezonlari yordamida sinf obyektlarini o'xshashlik darajasiga ko'ra tasniflash va ularning o'ziga xos belgilarini tanlash masalalari ko'rib chiqilgan.

Obyektlarning o'xshashlik darajasini aniqlash ko'plab amaliy sohalarda muhim vazifa hisoblanadi. Masalan, tibbiyotda kasalliklarni tashxislashda turli tasvirlarni o'zaro solishtirish, sanoatda esa mahsulotlarni avtomatlashtirilgan tarzda tasniflash yoki nosozliklarni aniqlash zarurati mavjud. Bu jarayonlarda obyektlarning muhim informativ belgilarini tanlash nafaqat tizim samaradorligini oshiradi, balki tahlil qilish jarayonini ham tezlashtiradi. Shuning uchun obyektlarning o'ziga xosligini va ularning informativ belgilarini aniqlash algoritmlari tahlil tizimlarining asosi hisoblanadi.

II. Asosiy qism

Mazkur tadqiqotda obyektlar o'rtasidagi o'xshashlik darajasini aniqlash orqali informativ belgilarni tanlash algoritmlari ishlab chiqildi. Obyektlarning muhimligini aniqlashda axborot o'lchov mezonlaridan foydalanish orqali sinf obyektlarining o'ziga xos belgilarini aniqlash va ularni tasniflash imkoniyati yaratildi. Axborot o'lchov mezonlari obyektlarning qaysi xususiyatlari ularning identifikatsiyasida muhim rol o'ynashini baholash imkonini beradi.

Ushbu yondashuvning muhim jihatlaridan biri shundaki, u katta hajmdagi ma'lumotlar bilan ishlashda eng zarur belgilarni tanlab, axborot oqimlarini optimallashtiradi. Masalan, turli xususiyatlarga ega obyektlar orasidan faqat eng muhimlarini aniqlash va ular asosida qaror qabul qilish jarayonini tezlashtirish imkoniyatini yaratadi. Bu jarayon, ayniqsa, ma'lumotlar tahlili, sun'iy intellekt va mashinali o'qitish texnologiyalarida katta ahamiyatga ega.

Mazkur tadqiqot ishida obyektlar muhimligini axborot o'lchov mezonlariga asoslanib baholash va informativ belgilar majmuasini tanlashning samarali algoritmini ishlab chiqish nazarda tutilgan. Ba bunga muvofiq, sinf obyektlari o'xshashlik darajalarini baholashni obyektlar muhimliklarini axborot o'lchov mezonlaridan foydalangan holda hal qilish va shu asnoda informativ belgilar majmuasini tanlash algoritmini ishlab chiqish quyidagicha amalga oshiriladi [5-7]:

Faraz qilaylik, ikkita X_p va X_q sinf obyektlarining farqini beruvchi λ vektor komponentalarini tanlashni taminlovchi $J(\lambda, X_p, X_q)$ mezon berilgan bo'lsin. Berilgan N - o'lchovli belgilar fazosidan shunday ℓ ($\ell \ll N$) o'lchovli fazoga o'tilsinki, hosil bo'lgan belgilar fazosida ikkita sinf obyektlari bir-birlaridan yaqqol ajralib tursin.

Ushbu masalani yechish uchun quyidagicha belgilashlar kiritamiz:

1. $I(\lambda, X_p)$ - bu funksional orqali λ **vektorga nisbatan** X_p sinf barcha obyektlari aro o'xshashlik darajalarining o'rtachasini;

2. $I(\lambda, X_q)$ - funksional orqali esa λ **vektorga nisbatan** X_q sinf barcha obyektlarining o'zaro o'xshashlik darajalarining o'rtachasini;

3. $I(\lambda, X_p, X_q)$ mezon orqali esa X_p va X_q sinflarning obyektlari aro yaqinliklarining o'rtachasini belgilaylik.

Obyektlar muhimligining axborot o'lchov mezoniga asoslangan informativ belgilar majmuasini tanlash algoritmi:

Quyida o'zgaruvchanliklar yoki xususiyatlarni tanlash jarayonida ma'lumotning muhimligini baholashga asoslangan algoritm taklif etiladi. Bunday algoritmlar, asosan, ma'lumot tahlili, sun'iy intellekt, ma'lumotlarni qayta ishlash va statistik modellashirish sohalarida qo'llaniladi.

Ushbu algoritmning asosiy qadamlari quyidagicha bo'lishi mumkin:

1-qadam. Ma'lumotlar tahlil qilinadi. Dastlab, mavjud ma'lumotlar bazasi tahlil qilinadi. Bu jarayonda ma'lumotlarning turi, hajmi va sifati inobatga olinadi. Demak, N - o'lchovli belgilar fazosida $x_i \in X$, $i = \overline{1, M}$, obyektlar beriladi. Bunda, $x_i = (x_i^1, x_i^2, \dots, x_i^N)$, $i = \overline{1, M}$, obyektlar klasterlarga ajralgan bo'lib, ular N - o'lchovli belgilar fazosida X_p sinflardan biriga tegishli bo'ladi. Har bir sinf m_p ta $x_{p1}, \dots, x_{pm_p}$ obyektlardan tashkil topgan $X = \bigcup_{p=1}^r X_p$. Odatda, bu qadamda ma'lumotlarga dastlabki ishlov beriladi.

2-qadam. Bu qadamda dastlab, obyektlarni o'xshashlik darajalarini aniqlash mezonidan foydalaniladi, bunda obyektlarni o'xshashliklarini aniqlash uchun $\mu(x_{pi}, x_{pk}) = (\mu^1(x_{pi}, x_{pk}), \mu^2(x_{pi}, x_{pk}), \dots, \mu^N(x_{pi}, x_{pk}))$ bul vektoridan foydalaniladi:

$$\mu^j(x_i, x_k) = \begin{cases} 1 & \text{agar } x_i^j = x_k^j, j = \overline{1, N}. \\ 0 & \text{aks holda.} \end{cases}$$

Bu yerda $\mu^j(x_{pi}, x_{pk}) = 1$ bo'ladi, agar ikkida obyektning mos komponentalari $x_i^j = x_k^j$ o'zaro teng bo'lsa, aks holda $\mu^j(x_{pi}, x_{pk}) = 0$ bo'ladi. So'ngra, belgilar o'lchovini baholash mezonini hisoblanadi. Bunda $\kappa(x_{pi}, x_{pk}) = \sum_{j=1}^N \mu^j(x_{pi}, x_{pk})$ kattalik orqali x_{pi}, x_{pk} obyektlarning o'xshashlik koeffitsiyentini belgilanadi. Bu ikkala x_{pi}, x_{pk} obyektning o'xshashlik darajalari $\nu(x_{pi}, x_{pk})$ orqali belgilanadi va u foizda quyidagicha hisoblanadi: $\nu(x_{pi}, x_{pk}) = \frac{\kappa(x_{pi}, x_{pk}) * 100\%}{N}$.

Bu jarayonda shunday δ soni beriladiki, bu orqali $\tilde{X}_p$ sinf obyektlari shakllantiriladi. Bunda $\forall x_{pi}, x_{pk}: \nu(x_{pi}, x_{pk}) \geq \delta$ bo'lsin. Ya'ni $\tilde{X}_p = \{x_{pi}, x_{pk}: \nu(x_{pi}, x_{pk}) \geq \delta \text{ sonidan katta bo'lsin, } i \neq k, p = \overline{1, r}\}$ sinf shakllanadi. Bu matematik ifodaning ma'nosi shakllantirilayotgan har bir sinf obyektlari aro o'xshashlik daraja, ularning nechta bo'lishidan qat'iy nazar oldindan berilgan δ sonidan kam bo'lmaslikni $\lambda \in \Lambda^\ell$ to'plamda talab etiladi. Natijada, talabga ko'ra sinf obyektlari shakllanadi.

3-qadam. Informativ belgilar majmuasi aniqlanadi. Ma'lumotlar ichidan eng muhim va ta'sirchan belgilar tanlnadi. Bu jarayon ma'lumotlarning turli o'lchov mezonlariga ko'ra saralanishi orqali amalga oshiriladi. Bu yerda quyidagi

$$\begin{cases} \tilde{X}_p = \{x_{pi}, x_{pk}, \lambda: \nu(x_{pi}, x_{pk}, \lambda) \geq \delta, i \neq k, p = \overline{1, r}\} \\ \lambda \in \Lambda^\ell = \left\{ \lambda: \sum_{j=1}^N \lambda^j = \ell, \lambda^j \in \{0, 1\}, j = \overline{1, N} \right\} \end{cases}$$

optimizatsiya masalasi yechiladi.

Bu yerda $\kappa(x_{pi}, x_{pk}, \lambda) = \sum_{j=1}^N \mu^j(x_{pi}, x_{pk}) \lambda^j$, $v(x_{pi}, x_{pk}, \lambda) = \frac{\kappa(x_{pi}, x_{pk}, \lambda) * 100\%}{N}$. Demak, shunday λ vektor tanlanishi kerakki, bunda sinflar soni kamayishi, $\tilde{X}_p$ sinf obyektlari orasidagi o'xshashlik berilgan δ dan kam bo'lmashligi kerak. Topilgan λ vektor komponentalari informativ belgilar majmuasini beradi. Masalan, bu yechimni topish uchun to'la tanlov algoritmini ishlatsak bo'ladi.

4-qadam. Belgilarni baholash va tanlash amalga oshiriladi. Tanlangan mezonlar asosida belgilarning ahamiyati baholanadi. Bu qadamda, statistik usullar va ma'lumot tahlili algoritmlaridan foydalaniladi. Odatda, quyidagi optimizatsiya masalasi yechiladi.

$$\begin{cases} v(x_{pi}, x_{pk}, \lambda) = \max_{\lambda \in \Lambda^\ell} \sum_{i \neq k=1}^{m_p} \sum_{k=i+1}^{m_p} \frac{\kappa(x_{pi}, x_{pk}, \lambda) * 100\%}{N} \\ \lambda \in \Lambda^\ell = \left\{ \lambda: \sum_{j=1}^N \lambda^j = \ell, \lambda^j \in \{0,1\}, j = \overline{1, N} \right\}. \end{cases}$$

Olingan ilmiy va amaliy natijalar aniq masalalarni yechimini topishdp qo'llaniladi. Tanlangan belgilar asosida ma'lumotlar tahlil qilinadi va modellashtirishda qo'llaniladi.

III. Xulosa

Tadqiqot natijalari obyektlar muhimligini axborot o'lchov mezonlari asosida baholash hamda informativ belgilar majmuasini tanlashga yo'naltirilgan algoritmik yondashuvning samaradorligini ko'rsatdi. Tadqiqot davomida sinf obyektlari orasidagi o'xshashlik darajasini aniqlashga asoslangan matematik apparat qo'llanilib, obyektlarning muhim informativ xususiyatlarini ajratish imkoniyati yaratildi. O'xshashlik koeffitsiyentlari va axborot muhimligi ko'rsatkichlari asosida boshlang'ich belgilar fazosidagi ortiqcha hamda kam informativlik ega bo'lgan belgilarni qisqartirish orqali ma'lumotlar hajmini optimallashtirishga erishildi.

Mazkur tadqiqot natijalari taklif etilgan yondashuvning mashinali o'qitish, timsollarni tanib olish va ma'lumotlarni intellektual qayta ishlash tizimlarida qaror qabul qilish jarayonining aniqligi va tezkorligini oshirishda muhim nazariy hamda amaliy ahamiyatga ega ekanligini ko'rsatdi.

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ALGORITHMS FOR IMPROVING IMAGE QUALITY IN THE PROCESS OF DISEASE DETECTION BASED ON FACIAL IMAGES

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Abstract. This article analyzes the mathematical foundations and experimental effects of image quality improvement algorithms in automatic disease detection systems based on facial images. The study systematically presents mathematical models of the CLAHE (Contrast Limited Adaptive Histogram Equalization), Bilateral Filter, Gamma correction, color normalization, and Super-Resolution methods. In particular, local histogram equalization, contrast restriction via the clip limit, calculation of spatial and intensity weights in a bilateral filter, the effect of gamma transformation on low-intensity regions, as well as the degradation model for super-resolution, SRCNN and Real-ESRGAN loss functions are described in formal mathematical expressions. In the experimental part, ResNet-50 and EfficientNet-B4 models were evaluated based on the ISIC 2020 RAF-DB image set. The results were analyzed using the repeated stratified k-fold validation methodology. The proposed complete preprocessing circuit provided an accuracy of $91.1 \pm 0.8\%$ and an AUC-ROC of 0.947 ± 0.012 in the EfficientNet-B4 model. The combination of CLAHE + Bilateral Filter achieved an AUC-ROC value of 0.921 ± 0.012 . Statistical analysis showed that the preprocessing chain yields a significant improvement compared to the base model.

Keywords: image enhancement, CLAHE, bilateral filter, gamma correction, super-resolution, facial analysis, disease detection, deep learning, k-fold validation, AUC-ROC.

Introduction. In recent years, the rapid development of computer vision, deep learning, and medical informatics has expanded the possibilities of automating medical diagnostic processes[1,2,3]. In particular, there is an increase in scientific research on identifying disease symptoms or conducting preliminary screening based on facial images[3,4]. Facial skin color, facial expressions, facial symmetry, swelling, spots, pigmentation, changes around the eyes, and other visual signs may be associated with certain dermatological, metabolic, neurological, and general clinical conditions. Automatic facial image analysis systems can be used as a supporting tool in practical medicine. Such systems do not replace the physician, but can be useful for early warning, remote monitoring, sorting large images, and supporting additional decision-making. At the same time, the reliability of such systems largely depends on the quality of the input image. Facial images taken under practical conditions often do not have the same quality[4]. Different lighting, camera sensor noise, low resolution, incorrect color balance, background effects, incorrect facial positioning, and compression artifacts directly affect the result of the diagnostic model. While deep learning models have strong feature separation capabilities, pathological features appear weak or blurred with noise in low-quality images. Therefore, preprocessing, that is, the stage of initial qualitative improvement of the image, is an important component in diseases detection systems based on facial images[5].

The main objective of this article is to mathematically and experimentally substantiate image quality improvement algorithms used prior to detecting disease symptoms based on facial images. The study describes the mathematical models of CLAHE, Bilateral Filter, Gamma correction, color normalization, and Super-Resolution algorithms, and compares their influence on the results of deep learning models.

Main Part

One of the most important problems in facial image-based disease detection systems is the instability of image quality. Outside of the clinical setting, such as in images taken with a mobile phone camera or webcam, the following factors are common. First, uneven lighting makes some parts of the face too bright and some parts too dark. This condition makes it difficult to identify skin color, spots, swelling, or signs of inflammation. Second, sensor noise, especially in low light, adds random pixel shifts to the image. Third, low spatial resolution eliminates fine visual features. Fourth, impaired color balance misrepresents color-related symptoms such as anemia, jaundice, and cyanosis. Fifth, data mismatch makes the model more likely to be a majority class. Therefore, the preprocessing stage is necessary not only for the visual improvement of the image but also for

increasing the generalizability of the model. Properly selected preprocessing algorithms enhance diagnostically significant features, reduce noise, and provide stable input data to the model.

Global Histogram Equalization. The image is labeled as follows:

$$I(x, y) \in \{0, 1, \dots, L - 1\}, \quad L = 256$$

where $I(x, y)$ is the pixel intensity in the (x, y) coordinate, and L is the number of intensity levels. The histogram for intensity k is determined as follows

$$h(k) = \#\{(x, y): I(x, y) = k\}, \quad k = 0, 1, \dots, L - 1.$$

Normalized histogram:

$$p(k) = \frac{h(k)}{MN},$$

where $M \times N$ — is the image size. Cumulative distribution function:

$$CDF(r) = \sum_{k=0}^r p(k).$$

Global histogram equalization transformation:

$$T_{\text{global}}(r) = (L - 1) \cdot CDF(r).$$

Resulting pixel value:

$$I_{\text{out}}(x, y) = T_{\text{global}}(I(x, y)).$$

Global histogram equalization improves overall contrast, but due to local lighting differences in facial images, overemphasis may occur in some areas. Therefore, the article uses CLAHE as a local approach.

CLAHE: Contrast Limited Adaptive Histogram Equalization. CLAHE usulida tasvir In the CLAHE method, the image is divided into $G_h \times G_w$ local blocks. For example, if tileSize=(8,8), this does not mean that each block is 8×8 pixels, but rather that the image is divided into 8×8 local tiles/blocks:

$$G_h = 8, \quad G_w = 8.$$

The size of each tile is approximately determined as follows:

$$H_{\text{tile}} = \frac{M}{G_h}, \quad W_{\text{tile}} = \frac{N}{G_w}.$$

Total number of pixels in the tile:

$$N_{\text{tile}} = H_{\text{tile}} \cdot W_{\text{tile}}.$$

Local Histogram for Tile:

$$h_{\text{tile}}(k) = \#\{(x, y) \in \Omega_{\text{tile}}: I(x, y) = k\}.$$

Local cumulative distribution:

$$CDF_{\text{tile}}(r) = \sum_{k=0}^r h_{\text{tile}}(k).$$

Local transformation:

$$T_{\text{tile}}(r) = \left\lfloor \frac{L - 1}{N_{\text{tile}}} \cdot CDF_{\text{tile}}(r) \right\rfloor.$$

Bilateral Filter. Bilateral Filter serves to preserve edges and important structures while reducing noise in the image[6]. The filtered value for the current pixel p is determined by:

$$I_{\text{BF}}(p) = \frac{1}{W_p} \sum_{q \in \Omega} I(q) f_s(\|p - q\|) f_r(|I(p) - I(q)|).$$

Spatial proximity function:

$$f_s(\|p - q\|) = \exp\left(-\frac{\|p - q\|^2}{2\sigma_s^2}\right).$$

The intensity similarity function:

$$f_r(|I(p) - I(q)|) = \exp\left(-\frac{|I(p) - I(q)|^2}{2\sigma_r^2}\right).$$

Normalization coefficient:

$$W_p = \sum_{q \in \Omega} f_s(\|p - q\|) f_r(|I(p) - I(q)|).$$

For a color image, the intensity difference is given by Euclidean distance in RGB space:

$$I_{BF}(p) = \frac{1}{W_p} \sum_{q \in \Omega} I(q) \exp\left(-\frac{\|p - q\|^2}{2\sigma_s^2}\right) \exp\left(-\frac{\|I(p) - I(q)\|_2^2}{2\sigma_r^2}\right).$$

Where,

$$\|I(p) - I(q)\|_2 = \sqrt{(R_p - R_q)^2 + (G_p - G_q)^2 + (B_p - B_q)^2}.$$

In the study, the practical parameters were selected as follows:

$$d = 9, \quad \sigma_s = 15, \quad \sigma_r = 75.$$

Here, d is the filter window diameter, σ_s is the spatial weight parameter, σ_r is the color or intensity difference sensitivity parameter[7].

Conclusion. This article examines the mathematical foundations and experimental effectiveness of image quality improvement algorithms for detecting diseases based on facial images. Formulas for the CLAHE, Bilateral Filter, Gamma correction, color normalization, and Super-Resolution methods are presented in formal mathematical form[8,9]. Experimental results showed that the EfficientNet-B4[10] model without preprocessing achieved an accuracy of $84.7 \pm 0.9\%$, while the proposed complete preprocessing circuit provided an accuracy of $91.1 \pm 0.8\%$ and an AUC-ROC of 0.947 ± 0.012 . The CLAHE + Bilateral Filter combination achieved an AUC-ROC value of 0.921 ± 0.012 . This indicates the importance of increasing local contrast and reducing noise while maintaining margins in medical classification systems based on facial images. The research results show that the preprocessing stage is not a simple technical process preceding the deep learning model, but an important scientific and practical component that affects the final diagnostic efficiency of the model. In the future, it is necessary to study the directions of scene-adaptive preprocessing, automatic parameter selection, medical image improvement based on a diffusion model, and integration with transformer architectures.

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BUG'DOY NAVLARI TANLANMASINING KLASSTERLI TAHLILI

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Annotatsiya. Ushbu maqolada bug'doy navlari va tizmalarini DBSCAN algoritmidan foydalanib klasterlar va shovqin obyektlarga ajratish masalasi qarang. Bunga ko'ra yumshoq bug'doy navlarining bir necha yillar davomida yig'ilgan seleksiya natijalarini birlashtirish asosida hosil qilingan umumlashtiruvchi tanlanmadagi navlarni o'xshashlik bo'yicha guruhlash va guruhlar qo'shilmagan (shovqin) navlarni aniqlash masalasi hal etilgan.

Klasterlash usullari o'qituvchisiz o'rgatish usullaridan hisoblanib, u berilganlarga ishlov berishni osonlashtiradi, tanlanmaning o'xshash obyektlarini guruhlariga jamlaydi va natijada har bir guruh bilan alohida ishlash imkoniyatini yuzaga keltiradi. Shuningdek, tanlanma hajmini

kamaytirish, o'ziga xos obyektlarni, ya'ni hech bir guruhga tegishli bo'lmagan obyektlarni ajratib olish, obyektlar to'plamlarining ierarxiyasini qurish va taksonomiya masalasini yechish imkoniyatlarini beradi.

Klasterli tahlil quyidagi asosiy vazifalarni bajaradi [1]:

- turlarga ajratish yoki klassifikatsiyani qayta o'tkazish;
- obyektlarni guruhlash uchun foydali konseptual sxemalar tadqiqoti;
- berilganlarni tadqiq qilish asosida gipotezalar topish;
- gipotezalarni tekshirish.

Ushbu maqolada bug'doy navlari va tizmalarini DBSCAN (Density-Based Clustering Algorithm) algoritmidan foydalanib klasterlar va shovqin obyektlarga ajratish masalasi qoraladi.

Bug'doy seleksiyasi masalasida ichki qonuniyatlardan biri bu – o'z xususiyatlariga ko'ra bir-biriga yaqin "joylashgan" yoki alohida boshqalardan ajralib qolgan bug'doy navlarini aniqlashdan iborat. Bu maqsadni amalga oshirishda DBSCAN – zichlikka asoslangan klasterlash algoritmidan foydalaniladi, bunda klaster berilganlar fazosida yuqori zichlikdagi nuqtalar sohasidan tashkil topadi va boshqa klasterlar bilan past zichlikdagi tutash sohalari orqali bog'lanadi degan g'oyaga asoslanadi.

DBSCAN algoritmidan foydalanib bug'doy navlari tanlanmasi ustida hisoblash experimentini o'tkazishdan maqsad – yumshoq bug'doy navlarining bir necha yillar davomida yig'ilgan seleksiya natijalarini birlashtirish asosida hosil qilingan umumlashtiruvchi tanlanmadagi navlarni o'xshashlik bo'yicha guruhlash va guruhlarga qo'shilmagan (alohida) navlarni aniqlash hamda natijalarga izoh berishdir.

Hisoblash eksperimenti uchun Janubiy dehqonchilik ilmiy-tadqiqot instituti (JDITI) dan 2014-2025-yillardagi seleksiya natijalari tanlanmalarini jamlash asosida shakllantirilgan o'quv tanlanmasi olindi. Tanlanmadagi nav va tizmalarining umumiy soni 1643 ta, tanlab olingan ko'rsatkichlar soni 11 ta.

Obyektlarni klasterlarga ajratishda quyidagilarga asoslaniladi [2]:

- obyektlar to'plamlarining tavsiflari bo'yicha klasterli tahlilda ularning tarqalish zichligi va topologik xususiyatlaridan foydalaniladi;
- obyektlarni taqsimlash zichligi bo'yicha guruhlash natijalari bir-biri bilan kesishmaydigan (kamida) ikkita sinfning o'quv tanlanmasi shaklida taqdim etiladi;
- klasterlarni tanlash uchun sinflardagi obyektlarning o'zaro bog'liqligiga oid topologik xususiyatlardan foydalaniladi;
- klasterlash natijalarini baholashda tanlanmadagi etalon obyektlarning minimal qoplamasidan foydalanish taklif etiladi;
- baholarning qiymati klaster ichidagi yaqinlik va klasterlararo farqlanish nisbati sifatida hisoblangan indeksni ifodalaydi.

Eksperiment. Bug'doy nav va tizmalarini tanlangan ko'rsatkichlarga ko'ra klasterlar va shovqin obyektlarga ajratishda $\varepsilon = 2.0453$, $MinPts = 2$ deb olingan holat o'rgatuvchi tanlanmadagi bug'doy navlarini 14 ta klaster va 140 ta shovqin obyektlarga ajratdi [3].

Bug'doy navlari orasidan shovqin sifatida aniqlangan 140 ta nav quyida keltirilgan sabablarga ko'ra birorta ham klasterdan joy olmagan:

– noyob ko'rsatkichlarga egaligi. Ayrim navlar mavjud ko'rsatkichlaridan biri yoki bir nechtaga ko'ra qolgan barcha navlardan sezilarli darajada farqlangan. *Masalan*, oqsil miqdorining keskin yuqoriligi, poyasining g'ayrioddiy uzunligi yoki vegetatsiya davrining juda qisqa bo'lishi kabilari;

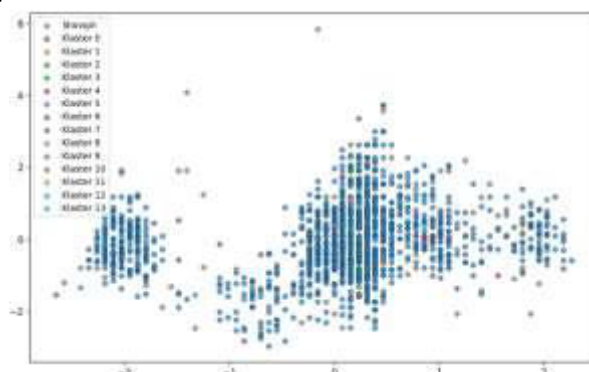
– o'tish oralig'idagi navlar. Ayrim navlar ikki klasterning hech biriga tegishli bo'lmagan holatda joylashib qolgan bo'ladi. Ya'ni ularning ko'rsatkichlari bir klaster uchun biroz kam, boshqasi uchun biroz ko'p bo'lishi mumkin;

– yillar bo'yicha o'zgaruvchan navlar. Ma'lumki, tajriba yillari oralig'ida iqlim sharoitlari o'zgarib turgan. Ba'zi navlar ayrim yillarda yuqori ko'rsatkichlarga ega bo'lib, boshqa yillarda esa past ko'rsatkichlarga ega bo'ladi;

– seleksiya uchun tajriba navlar. Yangi seleksiya tizmalari ko‘p hollarda o‘ziga xos ko‘rsatkichlarga ega bo‘ladi. Masalan, maqsadli gen o‘zgartirish natijasida birgina ko‘rsatkich sezilarli o‘zgarishi mumkin. Bu holat bunday turdagi navlarni mavjud klasterlardan ajratib, shovqin sifatida aniqlanishiga olib keladi;

– o‘lchov xatoliklari va ma‘lumotning ishonchliligi. Shovqin deb topilgan ayrim navlar ular haqidagi ma‘lumotlarni to‘plash jarayonida o‘lchov xatoliklariga uchragan bo‘lishi mumkin. Bunday texnik shovqinni agronomik shovqindan ajratish uchun qo‘shimcha tekshiruvlarni o‘tkazishga to‘g‘ri keladi.

Bug‘doy seleksiyasi masalalarini yechishda DBSCAN algoritmidan foydalanish ish samaradorligini sezilarli darajada oshiradi. Masalan, yillar davomida o‘z klasterini saqlab qolgan yoki o‘zgartirgan nav va tizmalarni algoritmdan olingan natijalarga ko‘ra osongina aniqlash mumkin. Misol uchun Bunyodkor, G‘ozg‘on, Grom kabi navlar bir necha yillar davomida o‘z klasterini o‘zgartirmagan. Buni algoritm asosida olingan natijalar ko‘rsatib turibdi. Natijalarning to‘g‘ri ekanliginida mutaxassislar tomonidan keltirilgan ilmiy-tadqiqot ishlari ham tasdiqlaydi. Ayrim nav va tizmalar yillar davomida o‘z xususiyatlarini o‘zgartirganligi sababli “Shovqin” obyektlar sifatida aniqlangan.



1-rasm. Klaster va shovqin obyektlarning vizualizatsiyasi.

Eksperiment natijalariga ko‘ra quyidagi xulosa va takliflarni keltirish mumkin:

– DBSCAN algoritmidan foydalanib, o‘ziga xos agronomik xususiyatlar to‘plamiga ega bo‘lgan 14 ta klaster aniqlandi. Ushbu natija bug‘doy navlarining genetik xilma-xilligi va seleksiya yo‘nalishlaridagi farqlanishlarni yaqqol ko‘rsatadi.

– navlar orasidan 140 ta shovqin navlar aniqlandi, bu ko‘rsatkich umumiy navlarning sezilarli qismini tashkil etadi. Ushbu navlarning shovqin sifatida aniqlanishi seleksiya jarayonlaridagi yangi izlanishlarni, unikal genotiplarni yoki tizimli o‘zgaruvchanlikni ko‘rsatishi mumkin.

– klasterlarning tarkibi navlar o‘rtasidagi xilma-xillikni aks ettiradi. Masalan, 1, 2, 6-klasterlar bir qator navlar uchun umumiy bo‘lgan ko‘rsatkichlarni ifodalasa, 4, 8, 10, 12-klasterlar o‘zida noyob xususiyatlarga ega bo‘lgan maxsus navlarni jamlagan.

– birinchi va oltinchi klasterlardan joy olgan navlar keng tarqalgan standart ko‘rsatkichlarga ega bo‘lganligi sababli, ulardan asosiy ishlab chiqarish maqsadlarida foydalanish tavsiya etiladi. Mazkur klasterlardagi navlar ustida gibridlashtirish ishlarini olib borish kelajakda hosildorlikni yanada oshirish imkonini beradi.

– to‘rtinchi klasterdan joy olgan navlar iqlim o‘zgarishi sharoitidagi strategik ahamiyatga ega bo‘lgan navlar hisoblanib, ularni qurg‘oqchilik xavfi yuqori bo‘lgan hududlarda ekiladigan navlar seleksiyasida donor sifatida ishlatish tavsiya etiladi.

– to‘qqizinchi klasterda joylashgan navlardan non ishlab chiqarish sanoati uchun mo‘ljallangan yuqori sifatli navlarni yetishtirish dasturlarida foydalanish tavsiya etiladi.

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FEDERATED LEARNING FOR PRIVACY-PRESERVING INTRUSION DETECTION IN DISTRIBUTED NETWORKS

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Abstract. The paper presents a federated learning framework for privacy-preserving network intrusion detection that simultaneously addresses statistical heterogeneity of client data, formal privacy guarantees, Byzantine robustness, and communication efficiency. The proposed framework, denoted FedIDS-DP-R, integrates Federated Averaging with (ϵ, δ) -differential privacy, a hybrid Krum and coordinate-wise trimmed-mean aggregation rule, and a Top-k sparsification with 8-bit quantization scheme. Experimental evaluation on the CIC-IDS2017 and NSL-KDD benchmark datasets confirms that the proposed approach attains detection performance within 1.5 percentage points of the centralized baseline, limits adversarial accuracy degradation to below 3.5% under 30% Byzantine clients, and reduces uplink communication traffic by a factor of approximately 24× relative to vanilla FedAvg.

Keywords: *federated learning, intrusion detection, differential privacy, Byzantine robustness, non-IID data, cybersecurity, distributed optimization.*

1. Introduction

The accelerating digital transformation of public administration, industry, and critical infrastructure has produced a sharp increase in the volume and variety of data exchanged across distributed information networks. The expansion of the attack surface and the growing sophistication of cyber threats have made traditional perimeter-based defenses insufficient. Consequently, the design of intelligent, adaptive, and scalable intrusion detection systems has become a central research problem at the intersection of applied mathematics, artificial intelligence, and information security.

Although deep learning has demonstrated remarkable performance in detecting both known and previously unseen network anomalies, the overwhelming majority of existing solutions rely on a centralized paradigm in which raw traffic from heterogeneous sources is aggregated on a single server. Such an architecture conflicts with contemporary data-protection regulations (GDPR and analogous national frameworks, including the Law of the Republic of Uzbekistan «On Personal Data»), introduces a single point of failure, and incurs prohibitive communication costs.

Federated Learning (FL), introduced by McMahan et al. in 2017 [1], offers a mathematically grounded alternative in which multiple clients cooperatively train a shared model while keeping raw data strictly local. However, its application to intrusion detection remains insufficiently explored. The principal unresolved challenges include: statistical heterogeneity of client data (non-IID), gradient-inversion privacy leakage, susceptibility to Byzantine and data-poisoning attacks, and residual communication overhead [2],[3],[4].

The aim of the present research is to design, mathematically justify, and experimentally validate a federated learning framework for privacy-preserving intrusion detection that simultaneously addresses the listed challenges. The **scientific novelty** consists in the integrated treatment of privacy, robustness, heterogeneity, and communication efficiency within a single framework, accompanied by a quantitative characterization of their mutual interactions under realistic non-IID conditions. The **practical significance** lies in providing a reproducible methodology that may be adopted by national CERTs, telecommunication operators, and security

operations centers for the deployment of collaborative AI-driven defense systems compatible with data-sovereignty requirements.

2. Materials and Methods

Problem formulation. Let K clients each hold a local dataset $D_k = \{(x_i, y_i)\}$, where $x_i \in \mathbb{R}^d$ denotes traffic-flow features and $y_i \in \{0, \dots, C-1\}$ is the class label. The global empirical risk to minimize is $F(w) = \sum (n_k/n) \cdot F_k(w)$, where $F_k(w)$ is the local cross-entropy loss. The local distributions $P_k(x, y)$ are non-IID, modelling realistic heterogeneity across organizational networks.

Datasets. Two benchmark datasets were used: CIC-IDS2017 (≈ 2.83 million flows, 78 statistical features, seven attack families) and NSL-KDD (≈ 148 thousand records, 41 features, four attack categories). Standard preprocessing (one-hot encoding, standardization, SMOTE balancing) was applied. Heterogeneity across $K = 10$ clients was emulated via Dirichlet partitioning with concentration parameter $\alpha \in \{0.1, 0.5, 1.0, 5.0\}$.

Model and training. The base classifier is a fully connected DNN (256–128–64 neurons, ReLU, batch normalization, dropout 0.3, softmax output). Federated training employs FedAvg with $E = 5$ local epochs, batch size $B = 64$, client-participation fraction $C = 0.3$, and $T = 100$ communication rounds.

Privacy mechanism. DP-SGD with per-sample gradient clipping (threshold $S = 1.0$) and Gaussian noise multiplier $\sigma = 1.1$ was integrated into the local update. The cumulative budget was tracked via the Rényi DP accountant, yielding $\epsilon \approx 4.2$ at $\delta = 10^{-5}$.

Robust aggregation. A hybrid rule combining Krum-based filtering with coordinate-wise trimmed mean (trimming ratio $\beta = 0.1$) was applied. Three attack types were simulated – sign-flipping (SF), label-flipping (LF), and additive Gaussian noise (GN) – with adversarial fractions in $\{10\%, 20\%, 30\%\}$.

Communication efficiency. Top- k sparsification ($k = 10\%$) with residual-error feedback and 8-bit quantization were used to reduce uplink traffic. Evaluation metrics: accuracy, precision, recall, F1-score, AUC, FPR, total transmitted volume (MB), and (ϵ, δ) . Each configuration was repeated five times; mean values are reported. The framework was implemented in PyTorch 2.1, Flower 1.6, and Opacus, on an NVIDIA RTX 4090 workstation.

3. Results

Table 1 summarizes detection performance on CIC-IDS2017 ($\alpha = 0.5$, no adversarial clients). The proposed FedIDS-DP-R framework attains F1-score within 1.5 percentage points of the centralized upper bound while preserving local data confidentiality and providing formal privacy guarantees.

Table 1 – Detection performance on CIC-IDS2017 (mean over five runs)

Model	Accuracy , %	Precision , %	Recall, %	F1-score, %
Centralized DNN	99.21	99.05	98.93	98.99
Local-Only	91.47	89.62	88.31	88.96
FedAvg (baseline)	98.43	98.21	97.96	98.08
FedIDS-DP-R (proposed)	97.86	97.54	97.18	97.36

Compared with the Local-Only baseline, federated collaboration yields an absolute F1-score improvement of approximately 8.4%, quantifying the «cost of isolation» incurred by non-cooperating organizations. The differential-privacy layer ($\sigma = 1.1$) reduces accuracy by less than 0.6% relative to vanilla FedAvg, providing a practical privacy–utility operating point ($\epsilon \approx 4.2$). Under sign-flipping attacks with 30% Byzantine clients, the proposed robust aggregation rule limits accuracy degradation to 3.14% (from 97.86% to 94.72%), whereas the unprotected FedAvg baseline

loses more than 40 percentage points. The combined Top-k sparsification and 8-bit quantization scheme reduces cumulative uplink traffic from 13.39 MB to 0.55 MB to reach the target F1-score of 97% – a 24.3-fold reduction.

4. Discussion

The obtained results demonstrate that the four challenges of federated intrusion detection – heterogeneity, privacy, robustness, and communication efficiency – can be addressed jointly without prohibitive trade-offs [5], [6]. The narrow performance gap with respect to the centralized baseline indicates that the collective exposure of multiple organizations to heterogeneous threats acts as an implicit form of data augmentation, consistent with observations by Mothukuri et al. [7] and Rahman et al [8]. The empirical breakdown threshold of the robust aggregation rule (approximately 30% Byzantine clients) is more conservative than the theoretical bound of one-half established by Yin et al. [9], which is attributable to the high dimensionality of the parameter space and to the additional perturbation introduced by differential privacy. The privacy budget $\epsilon \approx 4.2$ is consistent with major industrial deployments and with the recommendations of NIST for moderately sensitive applications. Limitations of the study include simulated federated conditions, reliance on legacy benchmark datasets, and the exclusion of advanced stealth-backdoor and collusive threat models – directions that are reserved for future work.

5. Conclusion

A federated learning framework for privacy-preserving intrusion detection has been proposed, mathematically justified, and experimentally validated. The framework integrates non-IID-aware Federated Averaging, (ϵ, δ) -differential privacy, hybrid Byzantine-resilient aggregation, and a communication-efficient transmission scheme. Experiments on CIC-IDS2017 and NSL-KDD confirmed detection performance within 1.5% of the centralized upper bound, formal privacy guarantees with $\epsilon \approx 4.2$, robustness under up to 30% Byzantine clients, and a 24-fold reduction in uplink traffic. The results provide a reproducible methodology aligned with contemporary digital-transformation and data-sovereignty requirements, applicable to national CERTs, telecommunication operators, and inter-organizational cybersecurity ecosystems. Future research will address asynchronous and resource-adaptive variants, stealth-backdoor robustness, and semi-supervised federated paradigms.

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EXOKARDIOGRAFIK ULTRATOVUSH TASVIRLARINI YAXSHILASHDA LANCZOS INTERPOLATSIYASI ASOSIDAGI YONDASHUV

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Annotatsiya: Mazkur ishda exokardiografik ultratovush tasvirlarida uchraydigan ayrim muammolar, xususan tasvir sifatining pastligi, spekl-shovqin va yurak chegaralarining noaniq ko'rinishi tahlil qilindi. Bunday holatlar amaliyotda chap qorincha konturlarini ajratishda qiyinchilik tug'dirishi va keyingi avtomatik tahlil natijalariga ta'sir qilishi mumkin.

Tadqiqot davomida Roboflow platformasidagi Echocardioc Dataset ma'lumotlar bazasidan foydalanildi. Tasvirlarga ishlov berish jarayoni bir necha bosqichda amalga oshirildi. Avvalo tasvir kontrasti yaxshilandi, keyin esa spekl-shovqinni kamaytirish uchun Adaptiv Perona–Malik diffuziya modeli qo'llanildi. Ushbu usul shovqinni kamaytirish bilan birga yurakning asosiy anatomik chegaralarini saqlab qolishga yordam berdi.

Keyingi bosqichda Lanczos interpolatsiyasi asosida tasvir aniqligini oshirish usuli sinovdan o'tkazildi. Tajribalar davomida ushbu yondashuv yurak konturlarini nisbatan aniqroq ko'rsatishi kuzatildi. Ayniqsa chap qorincha chegaralarining ravshanlashgani segmentatsiya jarayoni uchun foydali natija berdi.

Olingan natijalar PSNR, SSIM hamda Edge Preservation Index ko'rsatkichlari orqali baholandi. Tahlillar Lanczos asosidagi yondashuv exokardiografik tasvirlarga ishlov berishda samarali variantlardan biri bo'lishi mumkinligini ko'rsatdi.

Kalit so'zlar: exokardiografiya, ultratovush tasvirlari, Lanczos interpolatsiyasi, spekl-shovqin, Adaptiv Perona–Malik diffuziyasi, tasvir aniqligini oshirish, chap qorincha, segmentatsiya.

KIRISH

So'nggi yillarda tibbiyot sohasida raqamli tasvirlarga ishlov berish texnologiyalariga bo'lgan qiziqish sezilarli darajada ortib bormoqda. Ayniqsa yurak-qon tomir kasalliklarini erta aniqlash va baholashda exokardiografik ultratovush tasvirlari muhim diagnostik vositalardan biri hisoblanadi. Exokardiografiya yordamida yurakning anatomik tuzilishi, chap qorincha faoliyati, klapanlar holati hamda qon aylanishiga oid ko'plab ko'rsatkichlarni invaziv bo'lmagan usulda aniqlash mumkin [1].

Shunga qaramasdan, ultratovush tasvirlari boshqa tibbiy tasvirlarga nisbatan bir qator kamchiliklarga ega. Amaliyotda olingan exokardiografik tasvirlarda ko'pincha spekl-shovqin, past kontrast, tasvir aniqligining yetarli emasligi va anatomik chegaralarning xiralashishi kuzatiladi [2]. Ayniqsa chap qorincha endokard chegaralarining aniq ko'rinmasligi avtomatik segmentatsiya va keyingi diagnostik tahlil jarayonlarini murakkablashtiradi. Natijada yurak hajmini hisoblash, chiqarish fraksiyasini aniqlash va boshqa klinik ko'rsatkichlarni baholashda xatoliklar yuzaga kelishi mumkin.

Tasvir sifatini yaxshilash maqsadida turli super-resolution va interpolatsiya usullari taklif qilingan. Eng ko'p qo'llaniladigan usullar qatoriga Bicubic, Bilinear, Wavelet hamda Lanczos interpolatsiyasi kiradi [3]. Biroq ayrim usullar tasvirni haddan tashqari silliqlab yuborishi yoki aksincha ortiqcha artefaktlar hosil qilishi sababli exokardiografik tasvirlar uchun doim ham samarali natija bermaydi. Shu jihatdan yurakning anatomik konturlarini saqlab qolgan holda tasvir aniqligini oshirish dolzarb masalalardan biri bo'lib qolmoqda.

Mazkur tadqiqotda exokardiografik tasvirlar sifatini yaxshilash uchun Lanczos interpolatsiyasi asosidagi yondashuv taklif etildi. Tasvirlardagi spekl-shovqinni kamaytirish uchun Adaptiv Perona–Malik diffuziya modeli qo'llanildi. Ushbu usul tasvirdagi shovqinni kamaytirish bilan birga yurakning muhim anatomik chegaralarini saqlab qolishga imkon beradi [4]. Shuningdek, tasvir kontrastini yaxshilash maqsadida CLAHE algoritmidan foydalanildi.

Tadqiqot davomida Roboflow platformasidagi Echocardioc Dataset ma'lumotlar bazasi asosida tajribalar o'tkazildi [5]. Taklif etilgan yondashuvning samaradorligi PSNR, SSIM va Edge

Preservation Index kabi ko'rsatkichlar yordamida baholandi hamda boshqa klassik interpolatsiya usullari bilan qiyosiy tahlil qilindi.

Tadqiqotning asosiy maqsadi exokardiografik ultratovush tasvirlarida anatomik konturlarni saqlagan holda tasvir aniqligini oshirish va keyingi segmentatsiya jarayonlari uchun sifatli tasvir hosil qilishdan iborat.

MUAMMO VA MAVJUD USULLAR TAHLILI

Exokardiografik ultratovush tasvirlari yurak kasalliklarini aniqlash va baholashda muhim diagnostik vositalardan biri hisoblanadi. Ushbu usul yordamida yurakning anatomik tuzilishi, chap qorincha faoliyati, klapanlar holati va qon aylanishiga oid ko'rsatkichlarni invaziv bo'lmagan holda aniqlash mumkin [1]. Biroq amaliyotda olingan exokardiografik tasvirlar ko'pincha spekl-shovqin, past kontrast, fazoviy aniqlikning yetarli emasligi va anatomik chegaralarning xiralashishi bilan tavsiflanadi [2]. Ayniqsa chap qorincha endokard chegaralarining noaniq ko'rinishi segmentatsiya va keyingi avtomatik tahlil jarayonlarini murakkablashtiradi.

Ultratovush tasvirlarida uchraydigan spekl-shovqin signalning biologik to'qimalardan qaytishi natijasida yuzaga keladi. Ushbu shovqin tasvirda mayda donador strukturalar hosil qilib, foydali anatomik detallarni ajratishni qiyinlashtiradi [3]. Oddiy silliqlash filtrlari yordamida shovqinni kamaytirish mumkin bo'lsa-da, ular bilan birga yurakning muhim anatomik konturlari ham yo'qolib ketishi mumkin. Shu sababli exokardiografik tasvirlarga ishlov berishda shovqinni kamaytirish bilan bir qatorda konturlarni saqlab qoluvchi yondashuvlarga ehtiyoj mavjud.

Tasvir aniqligini oshirish uchun turli interpolatsiya usullari ishlab chiqilgan. Eng sodda usullardan biri Bilinear interpolatsiyasi bo'lib, u hisoblash jihatdan tez ishlaydi. Biroq ushbu usul tasvirni sezilarli darajada silliqlashtirib yuboradi va yuqori chastotali anatomik detallarni yetarli darajada saqlab qololmaydi [4].

Bicubic interpolatsiyasi Bilinear usuliga nisbatan yaxshiroq natija beradi. Ushbu usul yaqin atrofdagi 16 ta piksel asosida yangi qiymatlarni hisoblaydi va tasvirni tabiiyroq ko'rinishda tiklashga yordam beradi [5]. Shunga qaramasdan, Bicubic interpolatsiyasi ham ayrim hollarda yurak konturlarining nozik qismlarini xiralashtirib yuboradi.

Wavelet asosidagi super-resolution usullari tasvirni turli chastota komponentlariga ajratish orqali yuqori chastotali detallarni tiklashga harakat qiladi [6]. Nazariy jihatdan ushbu yondashuv samarali hisoblanadi, biroq ultratovush tasvirlarida ba'zan qo'shimcha artefaktlar hosil qilishi yoki spekl-shovqinni kuchaytirishi mumkin.

So'nggi yillarda Lanczos interpolatsiyasi yuqori chastotali konturlarni saqlash xususiyati sababli tasvir aniqligini oshirish masalalarida keng qo'llanila boshladi. Ushbu usul sinc funksiyasiga asoslangan bo'lib, anatomik chegaralarni boshqa klassik interpolatsiya usullariga nisbatan aniqroq tiklay oladi [7]. Ayniqsa exokardiografik tasvirlarda yurak konturlarining tabiiy shaklini saqlashda Lanczos interpolatsiyasi samarali natija ko'rsatishi mumkin.

Biroq faqat interpolatsiya usullarining o'zi spekl-shovqin muammosini to'liq bartaraf eta olmaydi. Shu sababli zamonaviy tadqiqotlarda shovqinni kamaytirish va konturlarni saqlash masalalari birgalikda ko'rib chiqilmoqda. Spekl-shovqinni kamaytirishda samarali yondashuvlardan biri Perona–Malik anisotrop diffuziya modeli hisoblanadi [8]. Ushbu model tasvirning silliq hududlarida diffuziyani kuchaytiradi, konturlar joylashgan hududlarda esa diffuziyani cheklaydi. Natijada shovqin kamayadi va anatomik chegaralar saqlab qolinadi.

Mavjud ilmiy ishlar tahlili shuni ko'rsatadiki, exokardiografik ultratovush tasvirlari uchun Lanczos interpolatsiyasi va Adaptiv Perona–Malik diffuziya modelining kombinatsiyalashgan holdagi qo'llanilishi yetarlicha o'rganilmagan. Ayniqsa segmentatsiyaga yo'naltirilgan enhancement pipeline yaratish masalasi dolzarbligicha qolmoqda.

Mazkur tadqiqotda aynan shu muammoni hal qilish maqsadida Lanczos interpolatsiyasi asosidagi super-resolution rekonstruksiya hamda Adaptiv Perona–Malik diffuziya modeli birlashtirilgan holda qo'llanildi. Taklif etilgan yondashuvning asosiy maqsadi exokardiografik tasvirlarda anatomik konturlarni saqlagan holda tasvir aniqligini oshirish va keyingi segmentatsiya jarayonlari uchun sifatli tasvir hosil qilishdan iborat.

TAKLIF ETILAYOTGAN YONDASHUV

Mazkur tadqiqotda exokardiografik ultratovush tasvirlarining aniqligini oshirish hamda anatomik konturlarni saqlab qolish maqsadida Lanczos interpolatsiyasi va Adaptiv Perona–Malik diffuziyasiga asoslangan kombinatsiyalashgan yondashuv taklif etildi. Taklif etilgan pipeline tasvir sifatini yaxshilash, spekl-shovqinni kamaytirish va keyingi segmentatsiya jarayonlari uchun qulay tasvir hosil qilishga qaratildi.

Taklif etilgan yondashuv bir necha ketma-ket bosqichlardan tashkil topdi. Dastlab exokardiografik tasvirlarning lokal kontrasti yaxshilandi. Chunki ultratovush tasvirlarida yurak devorlari va bo'shliqlari orasidagi intensivlik farqi ko'pincha past bo'ladi. Shu sababli tasvirlarga CLAHE algoritmi qo'llanildi. Ushbu usul lokal kontrastni oshirish orqali yurakning anatomik chegaralarini ravshanlashtirishga yordam berdi.

Keyingi bosqichda tasvirlardagi spekl-shovqinni kamaytirish uchun Adaptiv Perona–Malik diffuziya modeli qo'llanildi. Oddiy silliqlash filtrlari tasvirdagi foydali detallarni ham yo'qotishi mumkin bo'lsa, Perona–Malik diffuziyasi konturlarni saqlagan holda shovqinni kamaytirish imkonini beradi. Model tasvirning silliq hududlarida diffuziyani kuchaytiradi, anatomik chegaralar joylashgan hududlarda esa diffuziyani cheklaydi.

Perona–Malik diffuziya modeli quyidagi tenglama orqali ifodalanadi:

$$\partial t \partial I = \nabla * (c(\|\nabla I\|)\nabla I) \quad (1)$$

bu yerda: I – tasvir intensivligi, ∇I – gradient, $c(\|\nabla I\|)$ – diffuziya koeffitsienti.

Shovqindan tozalangan tasvirlarga keyingi bosqichda Lanczos interpolatsiyasi asosidagi super-resolution rekonstruksiya qo'llanildi. Lanczos interpolatsiyasi sinc funksiyasiga asoslangan bo'lib, yuqori chastotali konturlarni saqlash xususiyatiga ega. Ushbu usul orqali past o'lchamli tasvirlarning fazoviy aniqligi oshirildi hamda yurak konturlari tabiiyroq tiklandi.

Lanczos yadrosi quyidagi matematik ifoda bilan aniqlanadi:

$$L(x) = \begin{cases} \sin(x) \operatorname{sinc}\left(\frac{x}{a}\right), & |x| < a \\ 0, & \text{aks holda} \end{cases} \quad (2)$$

bu yerda: a – Lanczos oynasining radiusi, $\operatorname{sinc}(x)$ – sinus kardinal funksiyasi.

Ushbu tadqiqotda exokardiografik ultratovush tasvirlarida uchraydigan past sifat, spekl-shovqin va yurak chegaralarining noaniq ko'rinishi bilan bog'liq muammolar o'rganildi. Ayniqsa chap qorincha endokard chegaralarining xiralashishi keyingi avtomatik segmentatsiya jarayonlariga salbiy ta'sir qilishi aniqlandi.

Tadqiqot davomida tasvir sifatini yaxshilash uchun CLAHE, Adaptiv Perona–Malik diffuziyasi, Lanczos interpolatsiyasi va sharpness enhancement bosqichlarini o'z ichiga olgan yondashuv taklif etildi. Ushbu pipeline yordamida tasvirlardagi spekl-shovqin kamaytirildi, kontrast yaxshilandi va yurakning anatomik konturlari aniqroq ko'rinishga keltirildi.

Tajriba natijalari shuni ko'rsatdiki, Lanczos interpolatsiyasi exokardiografik tasvirlarda yuqori chastotali konturlarni boshqa klassik interpolatsiya usullariga nisbatan yaxshiroq saqlab qoladi. Adaptiv Perona–Malik diffuziyasi esa shovqinni kamaytirish bilan birga foydali anatomik chegaralarni yo'qotmasdan ishlov berishga yordam berdi. Natijada chap qorincha chegaralari ancha ravshanlashdi va tasvirlar segmentatsiya uchun qulayroq holatga keltirildi.

Baholash jarayonida PSNR, SSIM va Edge Preservation Index ko'rsatkichlari hisoblandi. Olingan natijalar taklif etilgan yondashuv exokardiografik tasvirlarga ishlov berishda barqaror va samarali natija berishini ko'rsatdi.

Umuman olganda, taklif etilgan usul exokardiografik ultratovush tasvirlari sifatini yaxshilash hamda keyingi avtomatik tahlil jarayonlari uchun foydali yechimlardan biri bo'lishi mumkin. Kelgusida ushbu yondashuvni real vaqt rejimida ishlovchi tizimlarda qo'llash va sun'iy intellekt asosidagi segmentatsiya modellari bilan birlashtirish rejalashtirilmoqda.

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OPTIK KOGERENT TOMOGRAFIYA TASVIRLARINI TASNIFLASHDA “REINFORCEMENT-BASED LEVERAGING TRANSFER LEARNING” YONDASHUVI

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Annotatsiya

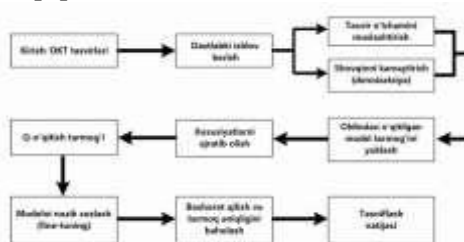
Ushbu ishda optik kogerent tomografiya (OKT) tasvirlarini ko'p sinfli tasniflash uchun Reinforcement-Based Leveraging Transfer Learning (RBLTL) nomli metodologik yondashuv taklif etiladi. Mazkur yondashuv transferli o'qitish va Q-o'qitish tarmog'i mexanizmlarini yagona tizimga birlashtirishga asoslanadi. Transferli o'qitish bosqichida oldindan o'qitilgan model tarmog'i OKT tasvirlaridan diagnostik ahamiyatga ega chuqur xususiyatlarni ajratib oladi. Q-o'qitish tarmog'i esa o'qitish jarayonida modelning qaror qabul qilish strategiyasi va giperparametrlarini mukofotga asoslangan tarzda moslashtiradi. Taklif etilgan yondashuv Normal, CNV, DME va Drusen sinflariga mansub OKT tasvirlarini tasniflash masalasiga yo'naltirilgan. Metodologik jihatdan RBLTL ma'lumotlar to'plamini tayyorlash, augmentatsiya, dastlabki ishlov berish, tasvir o'lchamini moslashtirish, shovqinni kamaytirish, oldindan o'qitilgan model tarmog'ini yuklash, xususiyatlarni ajratib olish, Q-o'qitish tarmog'i orqali adaptiv o'qitish, modelni nozik sozlash, bashorat qilish va tarmoq aniqligini baholash hamda tasniflash natijasi bosqichlaridan iborat..

Kalit so'zlar: OKT, transferli o'qitish, Q-o'qitish tarmog'i, RBLTL, oldindan o'qitilgan model tarmog'i, InceptionV3, DenseNet201, InceptionResNetV2, tasniflash.

Optik kogerent tomografiya oftalmologiyada to'r parda kasalliklarini aniqlash va baholashda keng qo'llaniladigan muhim tasvirlash texnologiyalaridan biridir. OKT tasvirlari to'r pardaning kesimli morfologiyasini aks ettirgani sababli diabetik makula shishi (DME), xoroidal neovaskulyarizatsiya (CNV), Drusen va normal retinal holatlarni farqlash imkonini beradi [1]. Biroq bunday tasvirlarni avtomatik tasniflashda bir qator metodologik muammolar mavjud. Tibbiy tasvirlar soni ko'pincha cheklangan bo'ladi, annotatsiya mutaxassis ishtirokini talab qiladi, ayrim kasallik sinflari morfologik jihatdan o'xshash ko'rinadi va chuqur neyron tarmoqlar noto'g'ri sozlangan hollarda o'quv ma'lumotlariga haddan tashqari moslashib qolishi mumkin.

Shu sababli OKT tasvirlarini avtomatik tahlil qilishda oddiy chuqur o'qitish modellaridan tashqari, moslashuvchan o'qitish strategiyalariga ehtiyoj mavjud. Transferli o'qitish bu borada muhim yechimlardan biri bo'lib, katta ma'lumotlar to'plamida oldindan o'qitilgan model tarmog'ini tibbiy tasvirlar tahliliga moslashtirish imkonini beradi [2]. Biroq statik transferli o'qitish yondashuvi har doim ham optimal giperparametrlarni avtomatik tanlay olmaydi. Shu nuqtai nazardan Q-o'qitish tarmog'i modelni o'qitish jarayonida parametrlarni moslashtirish, modelni nozik sozlash va qaror qabul qilish strategiyasini yaxshilash uchun qo'llanishi mumkin.

Ushbu ishda OKT tasvirlarini Normal, CNV, DME va Drusen sinflariga ajratish uchun Reinforcement-Based Leveraging Transfer Learning yondashuvi taklif etiladi. Yondashuvning asosiy g'oyasi shundan iboratki, oldindan o'qitilgan CNN model tarmog'i OKT tasvirlaridan chuqur xususiyatlarni ajratib oladi, Q-o'qitish tarmog'i esa ushbu xususiyatlar asosida o'qitish jarayonini adaptiv tarzda boshqaradi [3].



1-rasm. Taklif qilingan RBLTL yondashuvining sxemali ko'rinishi

Transferli o'qitish asosida xususiyatlarni ajratib olish

RBLTL yondashuvining birinchi asosiy komponenti **transferli o'qitish** hisoblanadi. Bu bosqichda katta hajmdagi umumiy tasvirlar bazasida **oldindan o'qitilgan CNN model tarmog'i** OKT tasvirlaridan diagnostik ahamiyatga ega chuqur xususiyatlarni ajratib olish uchun ishlatiladi. InceptionV3, InceptionResNetV2 va DenseNet201 asosiy **oldindan o'qitilgan model tarmoqlari** sifatida olish mumkin. Model esa tasvirdagi patologik belgilar, to'r parda qatlam deformatsiyasi, suyuqlik to'planishi, Drusen bilan bog'liq tuzilmalar va normal to'r parda ko'rinishlarga xos chuqur belgilarni ajratib oladi va xususiyatlarni ajratib olish jarayoni quyidagicha ifodalanadi:

$$F_{extracted} = M_{pre-trained}(I) \quad (1)$$

bu yerda $F_{extracted}$ – oldindan o'qitilgan model orqali ajratib olingan xususiyatlar, $M_{pre-trained}$ – oldindan o'qitilgan CNN model tarmog'i, I esa kiruvchi OKT tasviridir. Ushbu bosqichda OKT tasviri oddiy piksel qiymatlari majmuasi sifatida emas, balki kasallik sinflarini farqlashga xizmat qiluvchi chuqur xususiyatlar fazosida ifodalanadi.

Ajratib olingan xususiyatlar asosida sinf ehtimolliklari SoftMax funksiyasi orqali hisoblanadi:

$$P_{class}(y|F_{extracted}) = \frac{\exp(F_y)}{\sum_{i=1}^N \exp(F_i)} \quad (2)$$

bu yerda $P_{class}(y|F_{extracted})$ – OKT tasvirining y -sinfga tegishlilik ehtimolligi, F_y – shu sinfga mos logit qiymati, N esa umumiy sinflar sonidir. SoftMax bosqichi OKT tasvirini Normal, CNV, DME yoki Drusen sinflaridan biriga ehtimollik asosida birlashtirish imkonini beradi.

Xulosa

Ushbu ishda optik kogerent tomografiya tasvirlarini ko'p sinfli tasniflash uchun Reinforcement-Based Leveraging Transfer Learning (RBLTL) yondashuvi taklif etildi. Yondashuvning metodologik asosi transferli o'qitish va Q-o'qitish tarmog'i mexanizmlarini integratsiya qilishdan iborat. Transferli o'qitish bosqichida oldindan o'qitilgan CNN model tarmoqlari OKT tasvirlaridan chuqur xususiyatlarni ajratib oladi. Q-o'qitish tarmog'i esa o'qitish jarayonida parametrlar va qaror qabul qilish strategiyasini adaptiv tarzda moslashtiradi. Taklif qilingan RBLTL yondashuvi Normal, CNV, DME va Drusen kabi to'r parda holatlarni avtomatik tasniflash uchun moslashuvchan metodologik asos yaratadi.

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TASVIRLARNI SHOVQINDAN TOZALASH VA YUQORI ANIQLIKKA KELTIRISHNING AMALIY YONDASHUVLARI

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Annotatsiya. Mazkur tezisdá past sifatli raqamli tasvirlarni sun'iy intellekt yordamida shovqindan tozalash, super-rezolyutsiya qilish va foydalanuvchiga qulay veb-platforma orqali qayta ishlash yondashuvlari yoritiladi. Tadqiqot markazida Real-ESRGAN modeli, uning generativ raqib tarmoqlari asosidagi ishlash mexanizmi hamda tasvir teksturalarini tiklash imkoniyati turadi. Ishda tasvirlarni yaxshilash jarayoni dastlabki ishlov berish, model orqali tiklash, natijani solishtirish va sifatni baholash bosqichlari orqali tahlil qilinadi.

Kalit so'zlar: Real-ESRGAN, super-rezolyutsiya, tasvir sifati, shovqinni kamaytirish, generativ raqib tarmoqlari, AI Image Studio, PSNR, SSIM.

Raqamli texnologiyalar rivoji natijasida vizual axborotlar hajmi kundan-kunga ortib bormoqda. Mobil qurilmalar, kuzatuv kameralari, tibbiy diagnostika tizimlari, sun'iy yo'ldosh kuzatuvlari, elektron tijorat va arxivlashtirish jarayonlarida juda katta miqdordagi tasvirlar yaratiladi. Biroq amaliyotda bunday tasvirlarning barchasi ham yuqori aniqlikda bo'lavermaydi. Yorug'likning yetarli emasligi, kamera sifati, harakat xiraligi, JPEG siqish artefaktlari, sensor shovqini va uzatishdagi yo'qotishlar tasvir sifatini pasaytiradi. Natijada tasvirda mavjud bo'lgan muhim obyektlar, qirralar, teksturalar va mayda detallar yetarlicha ko'rinmay qoladi.

An'anaviy tasvir kattalashtirish usullari, masalan, nearest neighbor, bilinear yoki bicubic interpolatsiya, asosan piksellar orasidagi matematik qiymatlarni hisoblashga tayanadi. Bu usullar tasvir o'lchamini oshirishi mumkin, ammo yo'qolgan tafsilotlarni qayta tiklay olmaydi. Shuning uchun tasvir kattalashgan sari piksellashish, xiralik va blokli artefaktlar yanada yaqqol ko'zga tashlanadi. Zamonaviy chuqur o'qitish texnologiyalari esa tasvirni oddiy kattalashtirishdan tashqari, undagi semantik va teksturaviy bog'lanishlarni o'rganish orqali yetishmayotgan elementlarni mantiqiy tiklash imkonini beradi. Real-ESRGAN modeli super-rezolyutsiya yo'nalishidagi ilg'or yondashuvlardan biri bo'lib, u real hayotdagi buzilgan, shovqinli, siqilgan va xiralashgan tasvirlarni qayta tiklashga mo'ljallangan. Ushbu model tasvirni faqat kattalashtirib bermaydi, balki u orqali tasvirdagi qirralar, teksturalar, yuz elementlari, tabiiy obyektlar va murakkab rang o'tishlari yanada aniq ko'rinishga keltiriladi. Shu jihatdan Real-ESRGAN algoritmini foydalanuvchi uchun qulay veb-platformaga integratsiya qilish ilmiy va amaliy jihatdan dolzarb vazifa hisoblanadi.

Super-rezolyutsiya texnologiyasi past aniqlikdagi tasvirdan yuqori aniqlikdagi tasvir hosil qilishga qaratilgan. Bu jarayon oddiy masshtablashtirishdan tubdan farq qiladi, chunki unda model tasvirning ichki tuzilishini, obyektlar chegaralarini, yorug'lik va soya o'tishlarini, tekstura shakllarini o'rganadi. Real-ESRGAN modeli ESRGAN arxitekturasida rivojlantirilgan bo'lib, real dunyodagi tasvirlarda uchraydigan murakkab buzilishlarni tiklashga moslashtirilgan. Bunda modelga xiralashtirish, shovqin, JPEG siqish va boshqa artefaktlarni o'z ichiga olgan sintetik buzilgan tasvirlar beriladi hamda ularning yuqori sifatli variantlari bilan solishtirish orqali o'qitish amalga oshiriladi. Real-ESRGANning muhim xususiyati shundaki, u "blind super-resolution" yondashuviga yaqin turadi, ya'ni tasvirdagi buzilish turi oldindan aniq ma'lum bo'lmagan holatda ham natija bera oladi. Amaliy sharoitda tasvirlar ko'pincha bir necha bor siqiladi, qayta yuklanadi, tahrirlanadi yoki turli qurilmalar orqali uzatiladi. Bunday holatlarda buzilish bitta sababga emas, balki bir nechta omillarning qo'shma ta'siriga bog'liq bo'ladi. Real-ESRGAN shunday murakkab vaziyatlarda ham tasvirni nisbatan tabiiy ko'rinishda tiklashga intiladi.

Modelning generator qismi past sifatli tasvirni yuqori sifatli tasvirga aylantirishga xizmat qiladi. Diskriminator esa hosil qilingan tasvirni haqiqiy yuqori sifatli tasvirlardan ajratishga urinadi. Shu raqobatli o'qitish natijasida generator borgan sari tabiiyroq va ishonchliroq tasvir yaratishni o'rganadi. O'qitish jarayonida piksel darajasidagi yo'qotish, perceptual loss hamda GAN loss kabi yo'qotish funksiyalaridan foydalanish modelga aniqlik, tabiiylik va detallar o'rtasida muvozanatni saqlash imkonini beradi. Tasvir sifatini oshirish jarayoni bir nechta ketma-ket bosqichlardan tashkil

topadi. Birinchi bosqichda foydalanuvchi tasvirni tizimga yuklaydi. Yuklangan rasm formati, o'lchami, rang kanallari va shovqin darajasi dastlabki nazoratdan o'tkaziladi. Agar tasvir juda katta bo'lsa, xotira sarfini kamaytirish uchun uni bo'laklarga ajratib qayta ishlash maqsadga muvofiq bo'ladi. Agar tasvir shaffoflik kanaliga ega PNG formatida bo'lsa, RGB va alfa kanallarini alohida qayta ishlash texnik jihatdan to'g'ri yondashuv hisoblanadi.

Ikkinchi bosqichda tasvir Real-ESRGAN modeliga uzatiladi. Model tanlangan masshtab koeffitsiyenti, masalan, 2x, 4x yoki 8x bo'yicha tasvirni qayta quradi. Bunda model faqat yangi piksel qiymatlarini hisoblamaydi, balki obyektlarning tabiiy konturlarini, yuz detallarini, mato yoki devor teksturalarini, o'simlik, bino va boshqa elementlarning mayda tuzilishini ham tiklashga harakat qiladi. Ushbu bosqichda foydalanuvchi tanlagan rejim muhim ahamiyatga ega: standart rejim oddiy sifat oshirishga, HD+ rejimi maksimal aniqlikka, portrait rejimi inson yuzlarini tiklashga, creative rejimi esa tasvirda yetishmayotgan detallarni generativ tarzda boyitishga yo'naltiriladi. Uchinchi bosqichda natija foydalanuvchiga ko'rsatiladi. Zamonaviy platformalarda natijani faqat alohida rasm sifatida berish yetarli emas; foydalanuvchi asl va yaxshilangan tasvirni yonma-yon yoki slayder orqali solishtira olishi kerak. Bu yondashuv dastur natijasini ko'r-ko'rona qabul qilish emas, balki vizual tahlil qilish imkonini beradi. To'rtinchi bosqichda qayta ishlangan tasvir yuqori aniqlikda eksport qilinadi va foydalanuvchi uni yuklab oladi. Zarur holatda tizim oxirgi qayta ishlangan fayllarni tarix bo'limida saqlashi mumkin.

Real-ESRGAN modelini amaliy tizimga tatbiq etishda asosiy masala algoritmni oddiy foydalanuvchi uchun tushunarli va qulay shaklga keltirishdir. Kuchli neyron tarmoq faqat kod ko'rinishida qolsa, undan keng foydalanuvchilar foydalanishi qiyin bo'ladi. Shu sababli AI Image Studio tipidagi platforma frontend, backend, model serveri va fayl saqlash qatlamlaridan tashkil topgan yaxlit veb-tizim sifatida qaraladi. Front-end foydalanuvchi bilan muloqot qiladi, back-end so'rovlarni boshqaradi, model serveri tasvirni qayta ishlaydi, saqlash qatlami esa fayllarni xavfsiz joylashtiradi. Platformaning foydalanuvchi interfeysi soddalik va tezkorlik tamoyiliga asoslanishi kerak. Bosh sahifada xizmatning asosiy maqsadi, rasm yuklash tugmasi, demo ko'rish imkoniyati va natija namunasi aniq ko'rsatiladi. Ishchi panelda esa rasm yuklash maydoni, rejim tanlash, masshtab koeffitsiyentini belgilash, ishlov berish holati, natijani ko'rish va yuklab olish funksiyalari joylashadi. Bunday tuzilma foydalanuvchi tajribasini yaxshilaydi, chunki murakkab model parametrlarini bilmagan foydalanuvchi ham bir necha oddiy qadam orqali sifatli natijaga erisha oladi.

Tizimning orqa qismida GPU resurslarini samarali boshqarish muhim ahamiyatga ega. Katta hajmdagi tasvirlarni qayta ishlashda VRAM yetishmasligi mumkin, shuning uchun tiling strategiyasi qo'llaniladi: tasvir kichik bo'laklarga ajratiladi, har bir bo'lak alohida qayta ishlanadi va yakunda yagona rasm sifatida birlashtiriladi. Bu usul oddiy qurilmalarda ham katta tasvirlar bilan ishlash imkoniyatini oshiradi. Bundan tashqari, foydalanuvchi fayllarini xavfsiz saqlash, vaqtinchalik fayllarni avtomatik o'chirish, formatlarni tekshirish va zararli fayllardan himoyalash platformaning barqarorligi uchun zarur hisoblanadi.

Tasvir sifatini oshirish natijasini baholashda faqat ko'z bilan ko'rish yetarli emas. Ilmiy tahlilda miqdoriy ko'rsatkichlar ham qo'llanadi. PSNR ko'rsatkichi asl va tiklangan tasvir o'rtasidagi farqni signal va shovqin nisbati orqali baholaydi. Qiymat qanchalik yuqori bo'lsa, tiklangan tasvirda xatolik shunchalik kam deb qaraladi. SSIM esa tasvirlarning strukturaviy o'xshashligini, ya'ni yorqinlik, kontrast va tuzilma jihatidan yaqinligini o'lchaydi. Shu sababli PSNR va SSIM birgalikda qo'llansa, tasvir sifati haqida nisbatan to'liqroq xulosa chiqarish mumkin.

Biroq generativ modellar natijasini baholashda subyektiv ko'rish sifati ham muhimdir. Ba'zan PSNR yuqori bo'lishi mumkin, lekin rasm tabiiy ko'rinishligi ehtimoli mavjud. Aksincha, GAN asosidagi model tasvirni ko'zga yoqimli, aniq va teksturalarga boy qilib tiklashi mumkin, ammo piksel darajasida asl tasvirdan farq qilishi sababli ba'zi metrikalarda kutilganidek yuqori natija bermasligi mumkin. Shu bois Real-ESRGAN asosidagi tizimlarda miqdoriy metrikalar bilan birga foydalanuvchi bahosi va vizual solishtirish mexanizmini ham joriy etish maqsadga muvofiq.

Amaliy nuqtai nazardan bunday tizimlar turli sohalarda qo'llanishi mumkin. Raqamli arxivlarda eski fotosuratlarni tiklash, elektron tijoratda mahsulot rasmlarini sifatli ko'rsatish, xavfsizlik tizimlarida kuzatuv kamerasi tasvirlarini aniqlashtirish, tibbiyotda diagnostik tasvirlarning ko'rish sifatini yaxshilash, geoinformatikada sun'iy yo'ldosh tasvirlarini tahlilga tayyorlash ana shunday yo'nalishlar sirasiga kiradi. Ayniqsa, Sentinel-2A kabi ochiq manbali, lekin fazoviy aniqligi cheklangan tasvirlar bilan ishlashda super-rezolyutsiya algoritmlari obyektlarni ko'rish va tahlil qilish imkoniyatini kengaytiradi.

Xulosa o'rnida shuni aytish mumkinki, Real-ESRGAN modeliga asoslangan tasvirni yaxshilash tizimining ilmiy ahamiyati shundaki, u chuqur o'qitish, generativ raqib tarmoqlari, kompyuter ko'rish va veb-dasturlash yondashuvlarini yagona amaliy masalada birlashtiradi. Mazkur yondashuvda tasvir faqat matematik piksel massivlari sifatida emas, balki kontekst, tekstura va semantik belgilar yig'indisi sifatida tahlil qilinadi. Bu esa sun'iy intellekt yordamida vizual axborotni qayta ishlashning yangi bosqichini ifodalaydi.

Amaliy ahamiyati esa foydalanuvchiga murakkab AI modelidan maxsus dasturlash bilimlarisiz foydalanish imkonini berishida namoyon bo'ladi. Platforma rasm yuklash, rejim tanlash, natijani solishtirish va saqlash kabi oddiy funksiyalar orqali professional darajadagi qayta ishlash jarayonini taqdim etadi. Bunday tizim ta'lim, biznes, dizayn, jurnalistika, arxivlashtirish, xavfsizlik va ilmiy tadqiqotlarda foydali bo'lishi mumkin. Bundan tashqari, loyiha mahalliy sharoitda sun'iy intellekt asosidagi SaaS xizmatlarni ishlab chiqish tajribasini shakllantirishga xizmat qiladi.

XULOSA

O'tkazilgan tahlillar shuni ko'rsatadiki, Real-ESRGAN modeli past sifatli tasvirlarni tiklash, shovqinni kamaytirish va yuqori aniqlikka keltirishda an'anaviy interpolatsiya usullariga nisbatan samaraliroq yondashuv hisoblanadi. Modelning generativ raqib tarmoqlariga asoslangani tasvirdagi yetishmayotgan teksturalarni tabiiy ko'rinishda tiklash, qirralarni aniqlashtirish va vizual sifatni oshirish imkonini beradi. Ayniqsa, real hayotdagi noaniq buzilishlarga moslashuvchanligi ushbu algoritmnining amaliy qiymatini oshiradi.

AI Image Studio tipidagi platforma esa ushbu murakkab texnologiyani oddiy foydalanuvchi uchun qulay xizmatga aylantiradi. Tizimning rasm yuklash, rejim tanlash, natijani solishtirish, fayllarni saqlash va yuklab olish kabi funksiyalari uni to'laqonli amaliy mahsulot sifatida ko'rsatadi. PSNR, SSIM va vizual solishtirish kabi baholash yondashuvlari natijaning ilmiy asoslangan tahlilini ta'minlaydi. Kelgusida ushbu platformani video super-rezolyutsiya, mobil ilova, API xizmati va real vaqt rejimida ishlov berish imkoniyatlari bilan boyitish mumkin.

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**ИСПОЛЬЗОВАНИЕ ЧАТ-БОТОВ И ВИРТУАЛЬНЫХ АССИСТЕНТОВ В
ЛАБОРАТОРНОМ ПРАКТИКУМЕ ПО ИНФОРМАТИКЕ ПРИ СМЕШАННОМ
ОБУЧЕНИИ (НА ПРИМЕРЕ ПЛАТФОРМЫ DEEPSEEK)**

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Аннотация

В статье рассматриваются методические аспекты интеграции чат-ботов и виртуальных ассистентов на основе больших языковых моделей в лабораторный практикум по информатике для старших школьников (8–11 классы) в условиях смешанного обучения. На примере платформы DeepSeek анализируются дидактические возможности, сценарии применения и методические рекомендации по внедрению ИИ-ассистентов в школьный образовательный процесс.

Ключевые слова: искусственный интеллект в образовании, чат-бот, виртуальный ассистент, смешанное обучение, лабораторный практикум по информатике, DeepSeek, большие языковые модели, старшая школа.

Современный лабораторный практикум по информатике в условиях смешанного обучения сталкивается с дефицитом очного взаимодействия и необходимостью оперативной поддержки школьников при работе с симуляторами и виртуальными лабораториями [1]. Особенно остро эта проблема проявляется при больших размерах классов, когда учитель физически не может обеспечить индивидуальную помощь каждому ученику. Обучение программированию затрудняется из-за необходимости работы с большими группами и неоднородного предварительного уровня знаний, а школьники часто испытывают трудности при переводе описаний задач на естественном языке в работающий код.

Роль чат-ботов и виртуальных ассистентов. В последние годы большие языковые модели, такие как ChatGPT, GitHub Copilot и DeepSeek, всё активнее внедряются в образовательный процесс по информатике. Как показывает систематический обзор исследований, генеративный ИИ может эффективно поддерживать обучение программированию на начальном и продвинутом уровнях [2]. Чат-боты способны выполнять следующие дидактические функции: консультационную, навигационную, оценочную и рефлексивную.

Выбор платформы DeepSeek. В качестве объекта исследования выбрана платформа DeepSeek — современная большая языковая модель с открытым исходным кодом, доступная бесплатно через веб-чат и поддерживающая загрузку файлов и поиск в интернете. Большая языковая модель — это тип программы искусственного интеллекта, которая может распознавать и генерировать текст. Эти характеристики делают DeepSeek особенно перспективной для использования в школьном лабораторном практикуме по информатике.

Цель статьи: обосновать и описать методические подходы к интеграции чат-ботов (на примере DeepSeek) в лабораторный практикум по информатике для учащихся 8–11 классов в условиях смешанного обучения, а также предложить конкретные сценарии использования и методические рекомендации для учителей.

Определение чат-бота и виртуального ассистента. Под чат-ботом в контексте данной работы понимается программный агент, способный вести диалог с пользователем на естественном языке с использованием технологий обработки естественного языка и больших языковых моделей. Виртуальный ассистент представляет собой более широкое понятие, охватывающее разнообразные формы ИИ-поддержки, включая помощь в решении учебных задач, навигацию по образовательному контенту и выполнение инструментальных функций.

Дидактические функции чат-бота в лабораторном практикуме. На основе анализа педагогической литературы можно выделить четыре основные функции ИИ-ассистента в контексте лабораторного практикума по информатике:

1. Консультационная функция — оперативные ответы на вопросы школьников по синтаксису, семантике языка программирования, алгоритмам и методам отладки.

2. Навигационная функция — помощь в освоении интерфейса виртуальных лабораторий и симуляторов, а также предоставление инструкций по выполнению конкретных этапов лабораторной работы.

3. Оценочная функция — проверка промежуточных результатов выполнения заданий, выявление ошибок в коде, предоставление обратной связи и подсказок.

4. Рефлексивная функция — сбор обратной связи от учеников, анализ типичных затруднений, формирование рекомендаций по дальнейшему обучению.

3. Методическая модель интеграции DeepSeek в лабораторный практикум по информатике при смешанном обучении

Характеристика смешанного обучения в старшей школе. В рамках данной работы под смешанным обучением (blended learning) понимается образовательная модель, сочетающая очные занятия с учителем и самостоятельную работу школьника с использованием цифровых технологий, включая онлайн-лабораторные работы, симуляторы и виртуальные среды. Наиболее релевантными для лабораторного практикума по информатике являются модели «ротации станций» (station rotation), «гибкая модель» (flex model) и «перевернутый класс» (flipped classroom).

Структура лабораторного практикума с поддержкой DeepSeek. Предлагаемая методическая модель интеграции виртуального ассистента включает три взаимосвязанных этапа выполнения лабораторной работы.

На подготовительном этапе школьник использует DeepSeek для изучения теоретического материала и ознакомления с процедурой выполнения работы. Инструкция может быть загружена в веб-чат DeepSeek в виде PDF-файла или текстового документа. Ученик может задать DeepSeek вопросы для уточнения неясных моментов. Важной функцией является проверка готовности к работе: ассистент генерирует контрольные вопросы по теме, помогает повторить теорию и создаёт мини-тесты для самопроверки.

Непосредственное выполнение лабораторной работы, как основной этап, включает следующие виды взаимодействия с DeepSeek:

- помощь при отладке кода,
- объяснение алгоритмов и конструкций,
- генерация дополнительных учебных заданий,
- интерпретация выводов симуляторов и виртуальных лабораторий.

По завершении работы школьник оформляет отчёт, который может быть загружен в DeepSeek для автоматизированной проверки. Ассистент проверяет структуру отчёта, задаёт контрольные вопросы, выявляет возможные расхождения между кодом и его описанием. DeepSeek выдаёт рекомендации и замечания, но окончательное решение о корректировке ученик принимает самостоятельно.

Роли DeepSeek в очной и дистанционной частях смешанного обучения. В очной части DeepSeek используется в качестве вспомогательного инструмента для быстрых справок, позволяя учителю сосредоточиться на сложных вопросах. В дистанционной части DeepSeek становится основным средством оперативной поддержки, компенсируя отсутствие непосредственного контакта с учителем.

Сценарии применения DeepSeek в лабораторном практикуме по информатике для старших школьников, охватывающих основные потребности школьников при выполнении лабораторных работ по информатике.

Сценарий 1: Помощь при отладке кода. Школьник сталкивается с ошибкой в своём коде, которую не может устранить самостоятельно. Он копирует код и сообщение об ошибке в DeepSeek, получая разъяснение и возможное исправление. Пример запроса: Код: def

`average(x, y): return x + y / 2; print(average(10, 5))`. Ожидаемый вывод: 7.5. Реальный вывод: 12.5. Почему? Ответ DeepSeek: «Исправьте порядок операций: в вашем коде выполняется сначала деление $y/2$ ($5/2=2.5$), а потом сложение с x ($10+2.5=12.5$). Используйте скобки: `return (x + y) / 2`. Тогда результат будет 7.5.»

Сценарий 2: Генерация и проверка учебных заданий. Учитель или школьник запрашивает у DeepSeek дополнительные задания по конкретной теме для самопроверки. Пример запроса: «Сгенерируй 3 небольших задания по теме “Списки в Python” для начинающих с вариантами ответов.»

Сценарий 3: Объяснение алгоритмов и конструкций. Школьник не понимает, как работает сложный алгоритм. Он вставляет фрагмент кода в DeepSeek, получая пошаговое объяснение. Пример запроса: «Объясни этот код: `def fibonacci(n): return n if n <= 1 else fibonacci(n-1) + fibonacci(n-2)`. Как работает рекурсия для $n=4$?». Ответ DeepSeek: «Функция `fibonacci` вычисляет числа Фибоначчи рекурсивно. При $n=4$: сначала вызывается `fibonacci(4)`: проверка $n \leq 1 \rightarrow \text{false} \rightarrow$ возвращает `fibonacci(3)+fibonacci(2)`. `fibonacci(3) \rightarrow fibonacci(2)+fibonacci(1)`. `fibonacci(2) \rightarrow fibonacci(1)+fibonacci(0)`. `fibonacci(1)=1`, `fibonacci(0)=0`. Поднимаясь: `fibonacci(2)=1+0=1`, `fibonacci(3)=1+1=2`, `fibonacci(4)=2+1=3`.»

Сценарий 4: Подготовка к лабораторной работе (самопроверка). Школьник загружает в DeepSeek методические указания и просит сформулировать контрольные вопросы для подготовки. Пример запроса: «На основании приложенного файла “Лабораторная работа №3. Работа с файлами в Python” сгенерируй 10 вопросов для самопроверки. Вопросы должны проверять понимание, а не простое запоминание синтаксиса.»

Сценарий 5: Групповая работа и мозговой штурм. Группа школьников работает над проектом и использует DeepSeek как «третье мнение» для обсуждения архитектурных решений. Пример запроса: «Мы проектируем систему управления библиотекой. Предложи возможную структуру базы данных.»

Следует чётко разграничивать допустимое и недопустимое использование ИИ. DeepSeek — помощник для объяснения и отладки, а не средство автоматического решения заданий. DeepSeek, благодаря бесплатному доступу через веб-чат, поддержке загрузки файлов и высокому качеству ответов, является доступным и эффективным инструментом для поддержки школьников при выполнении лабораторных работ по информатике. Ключевыми факторами успешной интеграции являются: структурированная методическая модель (подготовительный — основной — заключительный этапы), обучение школьников эффективным стратегиям формулирования запросов, а также формирование навыков критической оценки ответов ИИ. Описанные сценарии использования DeepSeek (отладка, объяснение алгоритмов, генерация заданий, подготовка к работам, интеграция с симуляторами, групповая работа) позволяют системно применять виртуального ассистента в рамках школьного лабораторного практикума.

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TALABALARDA ILMIY JARAYON KO'NIKMALARINI RIVOJLANTIRISH.

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Mazkur maqolada talabalarga ilmiy jarayon ko'nikmalarini shakllantirish va ulardan samarali foydalanishni o'rgatishning pedagogik asoslari yoritilgan. Ilmiy jarayon ko'nikmalari talabalarning mustaqil fikrlashi, tahlil qilishi, muammoni hal etishi hamda ilmiy tadqiqot olib borish kompetensiyalarini rivojlantirishda muhim omil hisoblanadi. Maqolada ilmiy ko'nikmalarni rivojlantirish yo'llar tahlil qilingan.

Kalit so'zlar: ilmiy jarayon, ilmiy ko'nikmalar, tadqiqot faoliyati, kuzatish, tajriba, tahlil, kompetensiya, robototexnika, sun'iy intellekt, raqamli texnologiya, dasturiy ta'minot, sensor.

Kirish. Bugungi globallashuv va raqamli texnologiyalar rivojlanayotgan davrda oliy ta'lim tizimi oldiga talabalarning nafaqat nazariy bilimlarini oshirish, balki ularning ilmiy-tadqiqot faoliyatini samarali tashkil etish vazifasi ham qo'yilmoqda. Zamonaviy mutaxassisdan mustaqil fikrlash, muammoni ilmiy asosda hal etish, tahliliy yondashuv va innovatsion qarorlar qabul qilish kabi kompetensiyalar talab etiladi. Shu sababli talabalarga ilmiy jarayon ko'nikmalaridan foydalanishni o'rgatish bugungi ta'lim tizimining muhim yo'nalishlaridan biri hisoblanadi.

Ilmiy jarayon ko'nikmalari insonning atrof-muhitni ilmiy asosda o'rganishi, dalillarni yig'ishi, ularni tahlil qilishi va xulosalar chiqarishi jarayonida namoyon bo'ladi. Ushbu ko'nikmalar talabalarni oddiy bilim oluvchidan faol tadqiqotchiga aylantiradi. Ayniqsa, tabiiy fanlar, texnika, informatika hamda pedagogika yo'nalishlarida ilmiy jarayon ko'nikmalarining ahamiyati yanada yuqori hisoblanadi.

Tadqiqot ishinig maqsadi: Talabalarning ilmiy jarayon ko'nikmalarini rivojlantirishda raqamli texnologiyalar va sun'iy intellekt tizimining ahamiyatini tahlil qilish, samarali jihatlarini aniqlash va ta'lim jarayonida foydalanish holatini o'rganish.

Tadqiqot vazifasi: Ilmiy jarayon ko'nikmalarini shakllantirishda sun'iy intellekt tizimining imkoniyatidan informatika va raqamli texnologiyalarga oid bilimlarni o'rgatishda foydalanish holat(potensial) larini aniqlash.

Ilmiy jarayon ko'nikmalari — bu ilmiy tadqiqot olib borishda qo'llaniladigan amaliy va intellektual faoliyatlar majmuasidir. Ular yordamida talaba muammoni aniqlaydi, ma'lumot yig'adi, tajriba o'tkazadi, natijalarni tahlil qiladi va ilmiy xulosa chiqaradi. Ilmiy jarayon ko'nikmalaridan foydalanishni o'rgatish quyidagi bosqichlardan iborat::

1. Biron ilmiy jarayon ko'nikmasini bayon qilish;
2. Unga misollar keltirish;
3. Afzallik tomonlarini tushuntirish;
4. Ushbu ko'nikmani mashq qilish;
5. Ushbu ko'nikmani mashq qilgandan so'ng o'z fikrini bildirish.

Bugungi kunda raqamli texnologiyalar ilmiy jarayon ko'nikmalarini rivojlantirishda muhim vosita bo'lib xizmat qilmoqda. Jarayon ko'nikmalari ilmiy savodxonlikni rivojlantirish va baholashda kontekstga asoslangan savollar muhim ahamiyatga ega.

Masalan, talabalarga Robototexnikani o'rganishda sun'iy intellektning ahamiyati qanday ekanligini so'rash bilan ularning ilmiy savodxonlik ko'nikmalarini aniqlash mumkin. Avtomobillardan tortib, to maishiy texnika jihozlarigacha zamonaviy uskunalarining bir qismidir. Robototexnika kelajak haqida emas, balki hozirgi kun haqida, shuning uchun uni o'rganish rivojlanishda har qachongidan ham muhimdir. Talabalar robototexnika to'g'risida ma'lum darajada bilimga ega bo'lishlari kerak. Robototexnika bu robotlar va boshqa avtomatik tizimlarni yaratish, o'rganish va ulardan foydalanish bilan shug'ullanuvchi ilmiy va amaliy soha hisoblanadi. Ushbu sohada, texnologiya va mexanika asosida yaratilgan qurilmalar va robotlar o'zgaruvchanlik va ish xavfsizligi tizimi bilan farqlanadi.

Robotlarning asosiy tarkibiy qismlaridan biri bu dasturiy ta'minot, ya'ni robotning ishlashini boshqarish uchun dastur va alqoritmlardir.

-Sun'iy intellekt: Robotga o'z atrof-muhitini tushunish va unga mos javob berish imkoniyatini beruvchi texnologiyalar.

-Sensorlar va tizimlar: Robotning atrof-muhitni sezish imkoniyatini yaratadigan sensorlar (masalan, ko'rish, tegish, haroratni o'lchash).

Robototexnika zamonaviy dunyoda turli muammolarni hal qilish uchun muhim rol o'ynaydi va ko'plab sohalarda inqilobiy o'zgarishlarga olib kelmoqda.

Bunda asosiy qismlardan biri bo'lgan sun'iy intellektni talabalar chuqur va batafsil tushuntirish lozim. Sun'iy intellektsiz robotning imkoniyatini to'liq tasavvur qilish qiyin.

Talabalarda robototexnikani o'rganishda sun'iy intellektning ahamiyatini chuqur tahlil qilish orqali ilmiy jarayon ko'nikmalari rivojlanadi.

Ilmiy jarayon ko'nikmalari ikki guruhga, ya'ni asosiy va integrallashgan ilmiy jarayon ko'nikmalariga bo'linadi. Asosiy ilmiy jarayon ko'nikmalariga kuzatish, taqqoslash, o'lchash, tasniflash, ma'lumotlarni yig'ish, xulosa chiqarish kabilar kiradi.

Mazkur ko'nikmalar ilmiy faoliyatning boshlang'ich bosqichini tashkil etadi.

Integrallashgan ilmiy jarayon ko'nikmalariga gipoteza yaratish, tajriba loyihalash, o'zgaruvchilarni boshqarish, ma'lumotlarni tahlil qilish, ilmiy model yaratish, natijalarni izohlash kabi murakkab faoliyatlar kiradi.

Bu ko'nikmalar talabada yuqori darajadagi tafakkur va tahliliy yondashuvni shakllantiradi.

Talabalarda ilmiy jarayon ko'nikmalarini rivojlantirish quyidagi imkoniyatlarni yaratadi:

- Mustaqil fikrlashni rivojlantiradi;
- Talaba tayyor ma'lumotni yodlashdan ko'ra, uni izlab topishga va tahlil qilishga o'rganadi;
- Muammoli vaziyatlarni hal qilishni o'rgatadi;
- Ilmiy yondashuv asosida muammoning sabab va oqibatlarini aniqlash ko'nikmasi shakllanadi;
- Talabalarda tadqiqotchilik kompetensiyasini rivojlanadi.

Talaba tajriba o'tkazish va ilmiy loyiha yaratish malakasiga ega bo'ladi. Yangi g'oya va texnologiyalarni ishlab chiqishga qiziqish ortadi. Bo'lajak mutaxassis o'z sohasida ilmiy asoslangan qaror qabul qilish imkoniyatiga ega bo'ladi.

Talabalarda ilmiy jarayon ko'nikmalarini rivojlantirishda o'qituvchining pedagogik mahorati katta ahamiyatga ega. O'qituvchi ilmiy muhit yaratishi, talabalarni mustaqil izlanishga undashi, motivatsiya berishi, ilmiy manbalar bilan ishlashni o'rgatishi, tanqidiy fikrlashni rivojlantirishi zarur. Shuningdek, o'qituvchi ilmiy rahbar sifatida talabaga tadqiqot metodologiyasini o'rgatishi va ilmiy etikaga rioya qilishni tushuntirishi kerak.

Xulosa. Talabalarga ilmiy jarayon ko'nikmalaridan foydalanishni o'rgatish zamonaviy ta'limning ustuvor vazifalaridan biridir. Ushbu ko'nikmalar talabalarni mustaqil fikrlovchi, ilmiy asosda qaror qabul qiluvchi va innovatsion g'oyalarni ilgari sura oladigan mutaxassis sifatida shakllantiradi. Natijada oliy ta'lim tizimida raqobatbardosh, kreativ va ilmiy salohiyatga ega kadrlarni tayyorlash imkoniyati kengayadi.

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“METHODOLOGY FOR ENHANCING THE DIDACTIC MODEL OF THEORETICAL AND EXPERIMENTAL PHYSICS EDUCATION WITHIN AN ARTIFICIAL INTELLIGENCE FRAMEWORK”

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Abstract: This article discusses the issues of improving the didactic model of theoretical and experimental teaching of physics in higher education institutions using artificial intelligence technologies. The study analyzes the possibilities of individualizing the teaching process, increasing interactivity, and achieving deep assimilation of knowledge based on modern educational technologies, in particular neural networks. The authors propose a pedagogical and methodological model, justifying its components, functional capabilities, and practical significance. The results of the study show that it is possible to increase the effectiveness of teaching physics using artificial intelligence.

Keywords: artificial intelligence, neural networks, physics education, didactic model, experimental teaching, theoretical teaching, innovative pedagogy, adaptive teaching, digital technologies.

Introduction

In the context of modern globalization, the rapid development of science and technology significantly affects the education system. Digital transformation and artificial intelligence (AI) technologies are becoming key components of human activity, including higher education. Physics as a fundamental science combines theoretical knowledge and experimental research. However, traditional teaching methods (lectures, seminars, laboratory exercises) are often ineffective because they do not account for individual student differences. AI-based systems offer new opportunities: individualization of learning, real-time knowledge analysis, customized learning materials, and virtual modeling of physical phenomena. These systems also address issues of equipment shortages and enable objective automated assessment. Nonetheless, challenges remain, such as insufficient teacher training and technical infrastructure. An integrated approach — pedagogical, methodological, and technological — is necessary to improve the didactic model of physics education using AI.

Figure 1. Structural model of the teaching process based on artificial intelligence.

(image1.png)

Figure 2. Cyclic pedagogical model of physics education based on a modern approach.

(image2.png)

Main stages of the proposed model

The proposed model includes five main stages:

- 1.Diagnostic stage** – determining students' knowledge levels using AI.
- 2.Planning stage** – developing individual learning trajectories.
- 3.Teaching stage** – delivering theoretical knowledge and conducting virtual experiments via AI-based systems.
- 4.Control and analysis stage** – analyzing student results in real time.
- 5.Correction stage** – eliminating identified gaps.

The model combines theoretical and experimental training, develops students' independent work skills, and increases learning motivation. AI serves as an auxiliary tool, not a replacement for the teacher.

Experimental results

The study involved 100 students (50 control, 50 experimental).

1. Statistical data table

Groups	2 (Unsatisfactory)	3 (Satisfactory)	4 (Good)	5 (Excellent)	Total
Control Group	5	18	17	10	50
Experimental Group	1	9	22	18	50
Total	6	27	39	28	100

2.

2. Chi-square analysis The calculated χ^2 value exceeded the critical value at the given degrees of freedom and significance level. Therefore, the effectiveness of the AI-based didactic model is statistically proven.

3. Visual analysis (Diagrams)

Changes in groups (%):

Grade	Control Group	Experimental Group	Growth Indicator
5 (Excellent)	20%	36%	+16%
4 (Good)	34%	44%	+10%
3 (Satisfactory)	36%	18%	-18%
2 (Unsatisfactory)	10%	2%	-8%

Figure 1. Pie chart (image3.png) – In the experimental group, excellent (36%) and good (44%) grades together account for 80% of achievement; unsatisfactory results are minimal (2%).

Figure 2. Side-by-side comparison (image4.png) – Experimental group shows significantly more “Excellent” (18) and “Good” (22) grades than the control group.

Conclusion

The study developed and implemented a complete methodology for enhancing the didactic model of theoretical and experimental physics education using AI technologies in higher education. The model includes five key stages (diagnostics, planning, teaching, control and analysis, correction) with active AI integration. The pedagogical experiment demonstrated increased knowledge acquisition: the share of excellent grades rose from 20% to 36% (+16%), good grades from 34% to 44% (+10%), while satisfactory grades fell from 36% to 18% (–18%) and unsatisfactory from 10% to 2% (–8%). The combined increase in high grades (4 and 5) was 26%. Statistical analysis (chi-square) confirmed the significance of the results.

Virtual laboratories and interactive simulations helped students immediately apply theoretical knowledge in practice, developing critical thinking, problem analysis, and hypothesis testing. The automated assessment system saved teacher time and increased meaningful interaction. However, challenges remain: some students and teachers lack digital competence, and technical infrastructure requires further development. For widespread implementation, the study recommends: (1) advanced training for physics teachers in AI tools; (2) development of technical infrastructure for virtual labs; (3) methodological manuals on adaptive learning systems; (4) comparative studies.

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“ECOTUMAN” - AN AIR-PURIFYING ARTIFICIAL TREE DEVICE

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Abstract. This article discusses an artificial air-purifying tree device called “EkoTuman”. The article highlights the problem of air pollution in urban and industrial areas, its impact on human health, and the role of innovative technologies in solving this problem. It also describes the principle of operation of the device, the nano-filter technology used in it, the possibilities of using solar energy, and its ecological and social significance. The article analyzes the role of the “EkoTuman” device in reducing harmful gases in the air, improving the ecological environment, and creating comfortable conditions for the population. In addition, information is provided about the stages of project implementation, expected results, and its significance in ensuring environmental sustainability.

Keywords: artificial tree, air purification technology, ecology, atmospheric pollution, nano-filter, solar energy, green technologies, ecological innovation, air quality, carbon dioxide, sustainable development.

One of the most pressing problems in the world today is environmental problems, especially air pollution. As a result of the increase in industrial enterprises, the number of vehicles and the acceleration of urbanization processes, the amount of harmful gases in urban air is increasing. This situation poses a serious threat to human health. The increase in gases such as carbon dioxide (CO₂), nitrogen dioxide (NO₂), sulfur dioxide (SO₂) in the air has a negative impact not only on the ecological balance, but also on human health. Therefore, the development of innovative solutions aimed at purifying the air based on modern technologies is of great importance.

One such innovative project is “EcoTuman” – an artificial tree that purifies the air. This project combines ecology and modern technologies to ensure clean air in urban areas. Although ordinary trees have the ability to naturally purify the air, in some areas there are not enough trees or the possibility of planting them is limited. Especially in large urban centers, industrial areas and areas with heavy traffic, the level of air pollution is high. Therefore, an ecological device in the form of an artificial tree will help to partially solve this problem.

The main goal of the “EcoTuman” project is to reduce air pollution in urban and industrial areas, improve the ecological environment, and implement modern green technologies. This project will not only help solve environmental problems, but also serve to increase environmental culture in society. The project can also play an important role in combating climate change.

Several main tasks have been set within the framework of the project. Firstly, it is planned to improve atmospheric quality by reducing the amount of harmful gases in the air. Secondly, one of the important tasks is to protect the health of the population by filtering dust and harmful particles. Thirdly, it is planned to introduce environmentally friendly and sustainable energy sources through the use of solar energy in the device. In addition, the project also provides additional amenities for the population. For example, the device can be equipped with free Wi-Fi, phone charging ports, and structures that act as umbrellas. This will make using this device more convenient and useful.

One of the innovative aspects of the “EkoTuman” device is the use of nano-filter technology. This technology allows you to absorb harmful gases and particles in the air and release purified air. Another important feature of the device is that it works using solar energy. The body of the device is covered with solar panels, which generate electricity. Therefore, the device can operate independently, not depending on the power grid. This ensures energy efficiency and is

environmentally friendly. In addition, the design of the device is unique, it is designed to resemble a real tree. Artificial leaves are equipped with an LED lighting system, giving an aesthetic appearance in the evening. This makes the city landscape even more beautiful. The device is also equipped with a smart screen, which displays information about air quality in real time. As a result, citizens can have accurate information about the state of the environment. The principle of operation of the "EcoTuman" device is also simple and effective. The exterior of the device is covered with solar panels, which generate energy. The interior of the device contains a nano-filter and a carbon-absorbing catalyst. When the surrounding air passes through the device, harmful gases and dust particles are filtered out. Gases such as carbon dioxide are absorbed, and the resulting purified air is released outside. The device operates using solar energy during the day, and at night it continues to operate due to the energy stored in the battery.

If this project is implemented, it is estimated that one "EcoTuman" device will be able to perform the same function as about a hundred ordinary trees. This is especially important in areas where there is limited opportunity to plant trees. As a result, a clean and healthy environment will be created for residents, the city's ecology will improve, and air quality indicators will be monitored.

The project is planned to be implemented in several stages. In the first stage, research and design work will be carried out and a model of the device will be developed. In the second stage, one device will be installed and tested as a pilot project in the city center. In the third stage, the efficiency of the device will be monitored and the level of air purification will be studied. If the project is successful, the next stage will be to install such devices in other regions.

Cooperation with various organizations is also important during the implementation of the project. For example, local khokimiyats and environmental organizations can support this project. Universities and scientific research institutes can also contribute to the development of the project by providing scientific advice. Private companies can provide financial support on a sponsorship basis. In addition, young people and volunteers can also actively participate in promoting this environmental initiative.

The "EcoTuman" device can be installed in various places. For example, city squares, industrial areas, school and university courtyards, bus stops, and densely populated areas are the most suitable areas for such devices. In these places, the device not only cleans the air, but also serves as a convenient recreation and use point for people. Of course, the creation and installation of such an innovative device requires certain costs. According to rough estimates, the production and installation of one device will require approximately 13 thousand US dollars. These costs include the device frame, solar panels, nano-filter system, battery, smart screen, Wi-Fi module, as well as installation and maintenance work.

In conclusion, the "EcoTuman" project is an innovative solution that combines ecology and technology. With the help of this device, it is possible to purify urban air, address environmental problems, and develop modern green technologies. The project will not only serve to protect the environment, but will also make a significant contribution to creating a healthy and sustainable ecological environment for future generations.

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TA'LIM TIZIMIDA SUN'IY INTELLEKT TEXNOLOGIYALARINI QO'LLASH: IMKONIYATLAR VA ISTIQBOLLAR

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Annotatsiya

Mazkur maqolada ta'lim tizimida sun'iy intellekt texnologiyalarini qo'llashning nazariy asoslari, imkoniyatlari va muammolari tahlil qilingan. Tadqiqot davomida sun'iy intellekt asosida ishlovchi adaptiv o'qitish tizimlari, baholash va monitoring jarayonlari o'rganildi. O'quvchilarning bilim darajasini aniqlash, individual o'quv trayektoriyalarini shakllantirish va ta'lim samaradorligini oshirishda sun'iy intellektning roli ko'rsatib berildi. Tadqiqot natijalari sun'iy intellekt texnologiyalarining ta'lim tizimiga joriy etilishi o'quv jarayonini optimallashtirish, baholashning aniqligini oshirish hamda o'qituvchilar faoliyatini yengillashtirish imkonini berishini tasdiqlaydi.

Kalit so'zlar: sun'iy intellekt, ta'lim tizimi, adaptiv o'qitish, avtomatlashtirish, learning analytics, raqamli ta'lim, baholash tizimi, mashinaviy o'qitish, o'quv jarayoni

KIRISH

So'nggi yillarda dunyo miqyosida raqamli transformatsiya jarayonlari barcha sohalarda, xususan, ta'lim tizimida ham chuqur o'zgarishlarni yuzaga keltirmoqda [1,2]. Zamonaviy ta'lim jarayonini rivojlantirishda innovatsion texnologiyalar, ayniqsa sun'iy intellekt (SI) asosidagi yechimlar muhim o'rin egallay boshladi [3]. Sun'iy intellekt texnologiyalarining joriy etilishi ta'lim tizimini avtomatlashtirish, o'quv jarayonini individuallashtirish va bilimlarni baholash tizimini takomillashtirish imkonini bermoqda [4]. Sun'iy intellekt – bu kompyuter tizimlarining inson tafakkuriga xos bo'lgan o'rganish, tahlil qilish, qaror qabul qilish kabi funksiyalarni bajarish qobiliyatidir [5]. Ta'lim sohasida ushbu texnologiya o'quvchilarning bilim darajasini aniqlash, ularning o'zlashtirish tezligini tahlil qilish va individual o'quv trayektoriyalarini shakllantirishda keng qo'llanilmoqda [6]. Ayniqsa, adaptiv o'qitish tizimlari yordamida har bir o'quvchining ehtiyojlariga mos ta'lim muhitini yaratish imkoniyati paydo bo'ldi [7].

Hozirgi kunda sun'iy intellekt asosida ishlovchi tizimlar o'qituvchilarning faoliyatini ham sezilarli darajada yengillashtirmoqda [8]. Masalan, testlarni avtomatik yaratish, baholash, o'quvchilar faoliyatini monitoring qilish va tahlil qilish jarayonlari avtomatlashtirilmoqda [9]. Bu esa o'qituvchilarga ko'proq ijodiy va pedagogik faoliyatga e'tibor qaratish imkonini beradi [10]. Sun'iy intellekt texnologiyalarining ta'lim tizimiga joriy etilishi nafaqat o'qitish sifatini oshiradi, balki ta'limni boshqarish jarayonini ham yangi bosqichga olib chiqadi [11]. O'zbekiston Respublikasida ham ta'lim tizimini raqamlashtirish va sun'iy intellekt texnologiyalarini joriy etishga alohida e'tibor qaratilmoqda [12].

TADQIQOT METODOLOGIYASI

Mazkur tadqiqotda ta'lim tizimida sun'iy intellekt texnologiyalarini qo'llashning nazariy va amaliy jihatlarini o'rganish uchun kompleks yondashuvdan foydalanildi [3,6]. Tadqiqot jarayonida



1-rasm. Ta'limda sun'iy intellekt asosida

boshqaruv tizimining umumiy sxemasi

sun'iy intellekt asosida ishlovchi ta'lim tizimlarining ishlash prinsiplari, ularning imkoniyatlari va samaradorligi tahlil qilindi [7]. Tadqiqot metodologik asosini ilmiy abstraksiya, tahlil va sintez, induksiya va deduksiya, qiyosiy tahlil hamda tizimli yondashuv usullari tashkil etdi [13]. Ilmiy abstraksiya yordamida sun'iy intellektning ta'limdagi mohiyati umumlashtirildi, tahlil va sintez usullari orqali uning asosiy komponentlari ajratib ko'rib chiqildi [5]. Tadqiqot davomida sun'iy intellekt asosida ishlovchi ta'lim tizimining funksional modeli ishlab chiqildi [6].

Modelning ishlash jarayonida o'quvchilarning bilim darajasi, faoliyati va o'zlashtirish ko'rsatkichlari doimiy ravishda monitoring qilinadi [8]. Ushbu ma'lumotlar sun'iy intellekt algoritmlari yordamida tahlil qilinib, individual o'quv yo'nalishlari shakllantiriladi [7].

Tadqiqotda sun'iy intellekt tizimining asosiy tarkibiy elementlari aniqlanib, ularning o'zaro bog'liqligi tahlil qilindi [4].

Mazkur metodologik yondashuv orqali sun'iy intellekt texnologiyalarining ta'lim tizimidagi samaradorligi kompleks ravishda baholandi [14,15].

TAHLIL VA NATIJALAR



2-rasm. Sun'iy intellekt asosida

adaptiv o'qitish modeli

Ko'rsatkich	An'anaviy ta'lim tizimi	Sun'iy intellekt asosidagi ta'lim tizimi
O'qitish usuli	Yagona yondashuv asosida o'qitish	Shaxsiylashtirilgan, individual ta'lim usuli
Baholash jarayoni	Qo'lda, bi-xil testlar	AI yordamida avtomatlashtirilgan baholash
O'qituvchining yuklamasi	Intensiv, murakkab	Tahlil va monitoring jarayonlari avtomatlashtirilgan
O'quvchilarga moslashish	Har bir o'quvchi uchun bir xil dastur	O'quvchilarning ehtiyojlari va bilim darajasiga moslashish
Faollik va motivatsiya	Pasaygan darajada faollik	Interaktiv topshiriqlar va shaxsiy tavsiyalar orqali faollik
O'quvchilarga moslashish	Har bir o'quvchi uchun bir xil dastur	O'quvchilarning ehtiyojlari va bilim darajasiga moslashish
Faollik va motivatsiya	Pasaygan darajada faollik	Interaktiv topshiriqlar va shaxsiy tavsiyalar orqali faollik

1-jadval. Sun'iy intellekt asosida ta'lim tizimining asosiy ko'rsatkichlari

Tadqiqot jarayonida sun'iy intellekt texnologiyalarining ta'lim tizimidagi amaliy qo'llanilishi va uning samaradorligi tahlil qilindi. Olingan natijalar shuni ko'rsatdiki, sun'iy intellekt asosida tashkil etilgan ta'lim jarayonlari an'anaviy usullarga nisbatan yuqori samaradorlikka ega. Avvalo, sun'iy intellekt tizimlari yordamida o'quvchilarning bilim darajasini aniqlash va ularni individual tarzda baholash imkoniyati yaratildi. Adaptiv o'qitish tizimlari orqali har bir o'quvchining o'zlashtirish darajasi, qiziqishlari va xatoliklari tahlil qilinib, unga mos o'quv materiallari taklif etildi. Natijada o'quvchilarning bilimni o'zlashtirish darajasi sezilarli darajada oshgani kuzatildi. Tahlillar shuni ko'rsatdiki, sun'iy intellekt asosidagi tizimlar o'quvchilarning faolligini oshirishda ham muhim rol o'ynaydi. Interaktiv platformalar va moslashtirilgan topshiriqlar orqali o'quvchilar o'quv jarayoniga faol jalb etildi. Bu esa ularning mustaqil fikrlash qobiliyatini rivojlantirishga xizmat qildi. 1-jadval natijalariga ko'ra, sun'iy intellekt asosidagi ta'lim tizimida baholashning aniqligi va tezkorligi an'anaviy tizimga nisbatan yuqori ekanligi aniqlandi. Avtomatlashtirilgan baholash tizimlari inson omiliga bog'liq xatoliklarni kamaytirib, obyektivlikni ta'minladi. Shuningdek, 2-jadval asosida o'tkazilgan qiyosiy tahlil natijalari shuni ko'rsatdiki, sun'iy intellekt asosidagi ta'lim tizimida o'qituvchilarning ish yuklamasi kamaygan. Chunki baholash, monitoring va tahlil jarayonlari avtomatlashtirilgan. Bu esa o'qituvchilarga ko'proq ijodiy va pedagogik faoliyat bilan shug'ullanish imkonini berdi. 1-rasmda keltirilgan model asosida sun'iy intellekt tizimining ishlash jarayoni tahlil qilindi. Modelda o'quvchilardan olinadigan ma'lumotlar sun'iy intellekt algoritmlari orqali qayta ishlanib, natijaviy qarorlar qabul qilinishi ko'rsatildi. Ushbu tizim ta'lim jarayonini real vaqt rejimida boshqarish imkonini beradi.

Bundan tashqari, 2-rasmda ifodalangan adaptiv o'qitish modeli yordamida o'quvchilarning individual rivojlanish trayektoriyasi shakllantirilishi ko'rsatildi. Ushbu model orqali har bir o'quvchi uchun moslashtirilgan ta'lim muhiti yaratiladi, bu esa bilimlarni samarali o'zlashtirishga xizmat qiladi. O'tkazilgan tahlillar natijasida quyidagi asosiy natijalarga erishildi:

- sun'iy intellekt asosida ta'lim jarayonini individuallashtirish imkoniyati mavjud;
- baholash tizimining aniqligi va xolisligi oshadi;
- o'qituvchilarning ish yuklamasi kamayadi;
- o'quvchilarning faolligi va motivatsiyasi ortadi;
- ta'lim jarayonini real vaqt rejimida monitoring qilish imkoniyati yaratiladi.

XULOSA VA TAKLIFLAR

Mazkur tadqiqot ishida ta'lim tizimida sun'iy intellekt texnologiyalarini qo'llashning nazariy va amaliy jihatlari o'rganildi. Tadqiqot natijalari shuni ko'rsatdiki, sun'iy intellekt asosida

tashkil etilgan ta'lim jarayonlari an'anaviy ta'lim usullariga nisbatan yuqori samaradorlikka ega bo'lib, o'quv jarayonini optimallashtirishda muhim vosita hisoblanadi.

Tadqiqot davomida aniqlanishicha, sun'iy intellekt asosidagi ta'lim tizimlari o'quvchilarning faolligini oshiradi, ularning mustaqil fikrlash qobiliyatini rivojlantiradi hamda motivatsiyasini kuchaytiradi. Bundan tashqari, real vaqt rejimida tahlil qilish imkoniyati orqali ta'lim jarayonini samarali boshqarish imkoniyati yaratiladi.

Tadqiqot natijalari asosida quyidagi takliflar ilgari suriladi:

1. Ta'lim tizimida sun'iy intellekt texnologiyalarini keng joriy etish va uni normativ-huquqiy jihatdan qo'llab-quvvatlash zarur.
2. O'qituvchilar va pedagoglar uchun sun'iy intellekt bo'yicha maxsus malaka oshirish dasturlarini tashkil etish lozim.
3. Ta'lim muassasalarida zamonaviy texnik infratuzilmani rivojlantirish va raqamli platformalarni keng joriy etish tavsiya etiladi.
4. Sun'iy intellekt asosida ishlovchi milliy ta'lim platformalarini yaratish va rivojlantirish muhim ahamiyatga ega.
5. O'quvchilarning raqamli savodxonligini oshirish orqali sun'iy intellekt texnologiyalaridan samarali foydalanish imkoniyatlarini kengaytirish zarur.

Umuman olganda, sun'iy intellekt texnologiyalarini ta'lim tizimiga joriy etish zamonaviy ta'limning muhim yo'nalishlaridan biri bo'lib, u ta'lim sifatini oshirish, innovatsion muhitni shakllantirish va xalqaro raqobatbardoshlikni ta'minlashga xizmat qiladi.

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KORPORATIV TARMOQLARDA AXBOROTNI HIMOYA QILISHDA SUN'IY INTELEKT TEXNOLOGIYALARIDAN FOYDALANISH

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Annotatsiya. Ushbu maqolada korporativ tarmoqlarda axborotni himoya qilish, uning maxfiyligi, yaxlitligi va foydalanish imkoniyatini ta'minlash masalalari yoritilgan. Maqolada oddiy himoya usullari bilan birga sun'iy intellekt asosidagi yechimlar ham ko'rsatilgan. Unda anomalialarni aniqlash, foydalanuvchi faoliyatini tahlil qilish, tahdidlarni oldindan bilish va avtomatik javob berish imkoniyatlari bayon etilgan. Shuningdek, korporativ tarmoqlarni himoyalash vazifalari hamda Kerio Technologies Control, Ideco, UserGate, Check Point, Sophos va Fortinet kabi tizimlar misol sifatida keltirilgan.

Kalit so'zlar: sun'iy intellekt, identifikatsiya, autentifikatsiya, avtorizatsiya, kriptografiya, tarmoqlararo ekran, risk, IDS/IPS, SIEM, VPN, proksi-server, konfidensiallik, yaxlitlik, foydalana olishlik.

Korporativ tarmoq (KT)da axborotni himoya qilish - bu kompaniya resurslari, xizmat ma'lumotlari, tijorat sirlari hamda xodimlar va mijozlarning shaxsiy ma'lumotlarini himoyalashga qaratilgan tashkiliy, texnik va dasturiy choralar majmuidir. Zamonaviy korporativ infratuzilmalarda bulutli xizmatlar, IP telefoniya, masofaviy ish rejimi, elektron hujjat aylanishi va onlayn bank xizmatlaridan keng foydalanilishi axborot xavfsizligi (AX)ni yanada dolzarb masalaga aylantirmoqda.

An'anaviy himoya vositalari - tarmoqlararo ekran (TE), antivirus, Virtual Private Network (VPN), pochta shlyuzi va proksi-server - hanuz muhim ahamiyatga ega. Biroq tahdidlar soni va murakkabligi oshib borayotgan sharoitda oddiy imzo yoki qoidaga asoslangan nazorat ko'plab hujumlarni erta bosqichda sezmay qolishi mumkin. Shu sababli KTlarda sun'iy intellekt (SI) va mashinaviy o'qitish texnologiyalaridan foydalanish xavfsizlikni yangi bosqichga olib chiqmoqda.

KT xavfsizlik tizimi bir vaqtning o'zida bir nechta talablarni bajarishi kerak. Birinchidan, avtorizatsiya va identifikatsiyadan o'tgan foydalanuvchilar uchun xizmatlar uzluksiz ishlashi lozim. Ikkinchidan, ma'lumotlar yaxlitligi saqlanishi, ya'ni foydalanuvchiga yetkazilayotgan axborot to'liq va o'zgarmagan bo'lishi zarur. Uchinchidan, konfidensial ma'lumotlar faqat tegishli vakolat darajasiga ega shaxslargagina taqdim etilishi kerak.

Yirik KTlarda turli ishlab chiqaruvchilarning qurilmalari, bir nechta lokal tarmoqlar, ma'lumotlar bazalari va bulutli servislarning integratsiyasi xavfsizlikni boshqarishni murakkablashtiradi. Shuning uchun yagona boshqaruv markazi, markazlashgan audit, avtomatik monitoring va tezkor ogohlantirish mexanizmlari talab etiladi. SI aynan shu murakkab muhitda katta hajmdagi jurnal yozuvlari va tarmoq trafiginin tahlil qilish orqali xavfsizlik boshqaruvining samaradorligini oshiradi.

KTlarda hujumlardan himoyalashning beshta asosiy vazifasi SI vositalari bilan boyitilgan:

1-vazifa - umumiy IP-manzil va ochiq portlar orqali amalga oshiriladigan tashqi hujumlardan himoyalash. Bunda buzg'unchilar Secure Shell (SSH), Remote Desktop Protocol (RDP), File Transfer Protocol (FTP), Hyper Text Transfer Protocol (HTTP), Simple Mail Transfer Protocol (SMTP) kabi protokollar orqali tizimdagi ochiq portlarni aniqlashga va parol tanlash usullari bilan kirishga urinadilar. SIga asoslangan tahlil tizimlari portlarni skanerlash faolligi, noodatiy ulanishlar soni, manba manzillaridagi g'ayrioddiy xatti-harakatlarni aniqlab, hujum ehtimolini erta bosqichda baholay oladi. 1-rasmda SI asosida hujumlarni aniqlash modeli keltirilgan.



1-rasm. SI asosida hujumlarni aniqlash modeli

2-vazifa - masofaviy foydalanuvchilar uchun xavfsiz kirishni tashkil qilish. Amaliyotda VPN orqali kirish RDP yoki FTP portlarini ommaviy ochishdan ko'ra xavfsizroq hisoblanadi. SI yordamida masofaviy foydalanuvchi qurilmasi, joylashuvi, odatiy ish vaqti va sessiya parametrlari tahlil qilinib, riskga asoslangan autentifikatsiya qo'llanilishi mumkin. Natijada ruxsat etilgan foydalanuvchining hisob ma'lumotlari o'g'irlangan holatda ham shubhali sessiya qo'shimcha tekshiruvga yuboriladi.

3-vazifa - internet kanallarini boshqarish va trafikni optimallashtirish. Tashkilotda xodimlar soni ortgani sari kanalga tushadigan yuklama ham ortadi. Proksi-server va kontentni filtrlash bilan bir qatorda SI yordamida trafik sinflarga ajratilib, ishchi ilovalar, videokonferensiya, korporativ servislari va ko'ngilochar kontent oqimlari alohida nazorat qilinadi. Bu usul kanal resurslaridan oqilona foydalanish va xizmat sifatini saqlash imkonini beradi.

4-vazifa - kiruvchi va chiquvchi trafikni filtrlash. Elektron pochta, fayl almashinuvi va veb-trafik orqali viruslar, troyanlar, fishing havolalar va zararli skriptlar kirib kelishi mumkin. SI asosidagi filtrlash tizimlari matn mazmunini, Uniform Resource Locator (URL) xususiyatlarini, fayl

xatti-harakatini va foydalanuvchi reaksiyasini tahlil qilib, yangi va ilgari noma'lum tahdidlarni aniqlashda an'anaviy imzo bazalaridan ko'ra kengroq imkoniyat beradi.

5-vazifa - axborotlarni tahlil qilish va xodimlar faolligini monitoring qilish. KTda ayrim foydalanuvchi xatti-harakatlari insayder xavfini, ish samaradorligining pasayishini yoki ma'lumot sizib chiqish xavfini ko'rsatishi mumkin. User and Entity Behavior Analytics (UEBA) yondashuvi foydalanuvchining odatiy faoliyat profilini shakllantiradi va undan chetga chiqish holatlarini aniqlaydi. Bu esa tahdidlarni faqat sodir bo'lgandan keyin emas, balki boshlanish bosqichidayoq sezish imkonini beradi.

KTlarda SI bir nechta yo'nalishlarda qo'llaniladi. *Birinchi yo'nalish* - anomaliyalarni aniqlash bo'lib, bunda tizim normal trafik, odatiy sessiyalar, avtorizatsiya chastotasi va qurilmalar o'rtasidagi tipik aloqalarni o'rganadi. Keyin ushbu modeldan chetga chiqish holatlari tahdid sifatida baholanadi.

Ikkinchi yo'nalish - xavfsizlik hodisalarini korrelyatsiya qilish. Masalan, bir xil foydalanuvchi hisobidan qisqa vaqt ichida turli manzillardan kirish, shubhali domenlarga murojaat qilish, g'ayrioddiy hajmdagi fayllarni uzatish va tizim jurnalidagi ogohlantirishlar yagona xavfsizlik voqeasi sifatida bog'lanadi.

Uchinchi yo'nalish - avtomatik javob berish. Security Information and Event Management (SIEM) va Security Orchestration, Automation and Response (SOAR) platformalari yordamida shubhali sessiyani uzish, foydalanuvchini vaqtincha bloklash, zararli manzilni qora ro'yxatga kiritish yoki administratorga darhol hisobot yuborish kabi choralar avtomatlashtiriladi.

SI ning afzalligi shundaki, u katta hajmdagi ma'lumotlarni tez qayta ishlaydi, noto'g'ri ogohlantirishlarni kamaytiradi va xavfsizlik bo'yicha qaror qabul qilishni tezlashtiradi. Biroq natija model sifati, ma'lumotlarning to'liqligi va tizimning to'g'ri sozlanishiga bog'liq. Shuning uchun SI vositalari mutaxassis nazorati bilan qo'llansa, yuqori samaradorlik beradi.

KTlarning amaliy yechimlar va ularning imkoniyatlari kichik va o'rta biznes korxonalari uchun Kerio Control, Ideco va UserGate kabi yechimlar xavfsizlikni kompleks boshqarish, proksi, VPN, trafik filtrlash va hisobotlarni shakllantirish imkoniyatlarini beradi. Korporativ darajadagi infratuzilmalar uchun Check Point, Sophos va FortiGate oilasiga mansub yechimlar ko'proq mos keladi. Ushbu platformalar chuqurlashtirilgan inspeksiya, Intrusion Prevention System (IPS), markazlashgan boshqaruv, xavfsizlik siyosatlarini avtomatlashtirish va tahdidlar razvedkasi bilan integratsiya imkoniyatlariga ega.

Zamonaviy ishlab chiqaruvchilar SI va mashinaviy o'qitish yordamida noma'lum tahdidlarni aniqlash, zero-day hujumlarini kamaytirish, zararli URL va fayllarni tekshirish hamda administratorga aqlli tavsiyalar berish funksiyalarini rivojlantirmoqda. Shu sababli KT uchun himoya vositasini tanlashda faqat narx yoki quvvat emas, balki tahlil imkoniyatlari, doimiy yangilanadigan tahdid bazasi va markazlashgan nazorat ham hisobga olinishi kerak.

KTlarda axborotni himoya qilish ko'p qatlamli va moslashuvchan yondashuvni talab qiladi. TE, VPN, antivirus, proksi-server, IDS/IPS kabi an'anaviy vositalar asosiy himoya qatlamini yaratadi. SI esa bu himoyani kuchaytirib, anomaliyalarni tez aniqlash, tahdidlarni baholash, hodisalarini bog'lash va javob berishni avtomatlashtiradi. 2-rasmda SI asosidagi KT xavfsizligi arxitekturasini keltirilgan.



2-rasm. SI asosidagi KT xavfsizligi arxitekturasini

Arxitektura KTdagi kuzatuv, tahlil va avtomatik javob jarayonlarini yagona xavfsizlik konturida brlashtiradi.

Xulosa qilib shuni aytish mumkinki hech bir dasturiy yoki apparat vosita 100 foiz himoyani ta'minlamaydi. Eng samarali natija tashkiliy choralar, kuchli xavfsizlik siyosati, foydalanuvchilarni o'qitish, ehtiyot nusxa olish, audit va SIga asoslangan monitoring vositalarini birgalikda qo'llash

orqali erishiladi. Demak, KT xavfsizligining istiqbolli modeli - bu an'anaviy himoya vositalari va intellektual tahlil texnologiyalarining integratsiyalashgan majmuasidir.

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RAQAMLI TEXNOLOGIYALAR ASOSIDA HALOL TURIZM VA MEHMONXONA XIZMATLARINI RIVOJLANTIRISH

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Annotatsiya

Mazkur maqolada halol turizm va halol mehmonxona xizmatlarining zamonaviy rivojlanish tendensiyalari, ularning iqtisodiy va ijtimoiy ahamiyati tahlil qilinadi. Shuningdek, O'zbekistonda ziyorat turizmini rivojlantirish imkoniyatlari va halol xizmatlarni takomillashtirish yo'nalishlari asoslab berilgan.

Kalit so'zlar: halol turizm, ziyorat turizmi, mehmonxona xizmati, sertifikatlash, raqobatbardoshlik.

Kirish

Hozirgi kunda turizm sohasi jahon iqtisodiyotining eng dinamik rivojlanayotgan tarmoqlaridan biri hisoblanadi. Global turizm bozorida raqobatning kuchayishi sayyohlar ehtiyojlariga mos innovatsion xizmatlarni joriy etishni talab etmoqda. So'nggi yillarda musulmon sayyohlar sonining ortishi natijasida halol turizm alohida segment sifatida shakllandi. Halol turizm — bu musulmonlarning diniy qadriyatlarini va e'tiqodlariga mos xizmatlarni taqdim etishga qaratilgan turizm turi hisoblanadi.

Tadqiqotning ilmiy yangiligi shundan iboratki, unda halol mehmonxona xizmatlarining kompleks modeli O'zbekiston sharoitida tahlil qilinib, ularni rivojlantirishning amaliy yo'nalishlari taklif etilgan. Ilmiy tadqiqotlarga ko'ra, halol turizm global miqyosda yuqori iqtisodiy salohiyatga ega bo'lgan yo'nalishlardan biridir. Battour va Ismail tadqiqotlarida halol turizm konsepsiyasi, iste'molchilar xulq-atvori hamda xizmatlarga bo'lgan ishonch omillari tahlil qilingan. Ularning fikriga ko'ra, musulmon sayyohlar uchun asosiy talablar quyidagilardan iborat: halol ovqatlanish, ibodat qilish imkoniyati, genderga mos xizmatlar hamda axloqiy muhit. Shuningdek, Razzaq, Hall va Prayag tomonidan olib borilgan tadqiqotlarda xizmat sifati, marketing strategiyalari va madaniy qadriyatlar halol mehmonxonalar rivojlanishida muhim omillar ekanligi asoslab berilgan.

Mazkur tadqiqotda kompleks yondashuv qo'llanildi:

- ilmiy adabiyotlarni tahlil qilish;
- sifatli tadqiqot (intervyular);
- mutaxassislar fikrini o'rganish;
- xorijiy tajribalarni taqqoslash.

Ushbu metodlar halol turizmning rivojlanish xususiyatlarini chuqur tahlil qilish imkonini berdi. Tadqiqot natijalari shuni ko'rsatadiki, halol va ziyorat turizmi jahon miqyosida eng tez rivojlanayotgan yo'nalishlardan biridir. Ushbu soha iqtisodiy o'sish, yangi ish o'rinlari yaratish va infratuzilmani rivojlantirishga xizmat qilmoqda. O'zbekistonda ham so'nggi yillarda sayyohlar oqimi sezilarli darajada oshgan. Xususan, qo'shni davlatlardan kelayotgan turistlar sonining ortishi ziyorat turizmining rivojlanayotganidan dalolat beradi.

Halol mehmonxonalarining asosiy xususiyatlari:

- halol sertifikatlangan oziq-ovqat;
- spirtli ichimliklarning mavjud emasligi;

- ibodat uchun qulay sharoit;
- xizmatlarning diniy va madaniy talablarga mosligi.

Tahlillar shuni ko'rsatadiki, halol sertifikatlash tizimi sayyohlar ishonchini oshiradi va turizm obyektlarining raqobatbardoshligini kuchaytiradi. Halol turizm zamonaviy turizm bozorining istiqbolli yo'nalishlaridan biri hisoblanadi. U iqtisodiy samaradorlik bilan bir qatorda, madaniy va ma'naviy qadriyatlarni rivojlantirishga xizmat qiladi. O'zbekistonda halol turizmni rivojlantirish xalqaro turizm bozorida raqobatbardoshlikni oshirish va iqtisodiy o'sishni ta'minlashda muhim ahamiyatga ega.

- halol turizmni davlat tomonidan qo'llab-quvvatlashni kuchaytirish;
- xalqaro standartlarga mos sertifikatlash tizimini joriy etish;
- innovatsion va barqaror turizm texnologiyalarini rivojlantirish;
- xorijiy tajribalarni amaliyotga tatbiq etish.

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OLIY TA'LIMDA FIZIKA FANINI O'QITISHDA GIBRID LABORATORIYALAR VA KOGNITIV TAHLIL: EMPIRIK NATIJALAR VA ZAMONAVIY TENDENSIYALAR

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Kirish va muammoning dolzarbligi Zamonaviy oliy ta'lim tizimida fizika kabi fundamental fanlarni o'qitishda nazariy bilimlarni amaliy ko'nikmalar bilan bog'lash doimiy pedagogik muammo bo'lib kelgan. Garchi an'anaviy laboratoriyalar bu borada muhim rol o'ynasa-da, ularning texnik va vaqt jihatidan cheklovlari talabalarning mustaqil izlanish doirasini ma'lum ma'noda toraytiradi. So'nggi yillarda ta'limga kompyuter simulyatsiyalari va elementar sun'iy intellekt (SI) yechimlarining kirib kelishi bu masalaga yangicha yondashuvlarni taqdim etmoqda. Xususan, an'anaviy va virtual muhitni o'zida jamlagan gibril laboratoriyalarning joriy etilishi talabalardagi kognitiv yuklamani optimallashtirish va fanni o'zlashtirish dinamikasini oshirishga xizmat qiladi.

Metodologiya va tadqiqot obyekti Ushbu gibril yondashuvning amaliy samaradorligini o'rganish maqsadida jami 435 nafar talaba qamrab olingan empirik tadqiqot amalga oshirildi. O'quv jarayonida talabalar an'anaviy laboratoriya mashg'ulotlari bilan bir qatorda Multisim va Proteus kabi interfaol virtual platformalardan faol foydalanishdi. O'zlashtirish dinamikasi va kognitiv faollikdagi o'zgarishlarni aniq baholash uchun semestr boshi va yakunidagi ko'rsatkichlar o'zaro solishtirildi. Natijalarning ishonchliligini ta'minlash maqsadida ma'lumotlar Styudentning T-kriteriyasi (T-test) yordamida statistik tahlildan o'tkazildi.



1-rasm. Gibrid va an'anaviy laboratoriya sharoitida tahsil olgan talabalar ($n=435$) kognitiv o'zlashtirish dinamikasining qiyosiy ko'rsatkichlari.

Tahlil va muhokama Tadqiqotning statistik ma'lumotlari virtual va gibrid muhitda ta'lim olgan guruhlarda fizik jarayonlarni modellashtirish, sabab-oqibat bog'lanishlarini tushunish va masalalarni yechish ko'nikmalari sezilarli darajada ($p < 0.05$) o'sganini ko'rsatdi. Olingan bu natijalar sohadagi qator yetakchi xalqaro tadqiqotlar xulosalarini amaliy jihatdan tasdiqlaydi. Jumladan, T. de Jong va hammualliflar (2013) o'zlarining fundamental maqolasida fizika ta'limida virtual laboratoriyalar an'anaviy usullarni to'liq siqib chiqarmasligini, aksincha, ularni to'ldirib, talabalarga xavfsiz va cheksiz tajriba o'tkazish maydonini taqdim etishini ta'kidlagan edilar.

Boshqa tomondan, virtual simulyatsiyalarning samaradorligi fanni vizualizatsiya qilish imkoniyatlari bilan chambarchas bog'liq (Rutten va boshq., 2012). Jarayonlarni makro va mikro darajada kuzatish talabani abstrakt qonuniyatlarni tezroq idrok etishiga yordam beradi. G. J. Hwang va Y. F. Tu (2021) ko'rsatib o'tganidek, bu kabi raqamli platformalarga sun'iy intellekt vositalarini (masalan, o'zlashtirishni bashorat qiluvchi va tahlil qiluvchi algoritmlarni) integratsiya qilish orqali butunlay moslashuvchan, individual ta'lim trayektoriyasini yaratish mumkin bo'ladi. Bizning tadqiqotda kuzatilgan ijobiy dinamika ham bevosita simulyatsiya dasturlarining talaba xatolarini zudlik bilan ko'rsatib beruvchi va tahlilga undovchi xususiyatlari bilan bog'liqdir.

Xulosa: Olib borilgan statistik va kognitiv tahlillar fizika kurslarida gibrid laboratoriya modelini qo'llash yuqori pedagogik samaradorlikka ega ekanligini ko'rsatadi. 435 nafar talaba ishtirokidagi empirik ma'lumotlar shuni tasdiqlaydiki, an'anaviy amaliyotni zamonaviy dasturiy ta'minotlar bilan uyg'unlashtirish kognitiv qabul qilishni yaxshilaydi. Kelgusida mazkur jarayonga qoida-asosidagi va intellektual SI modellarini joriy qilish orqali oliy ta'lim sifatini yangi bosqichga olib chiqish imkoniyati mavjud.

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IQTISODIYOT YO'NALISHI TALABALARI UCHUN MATEMATIK TUSHUNCHALARNI O'RGATISHDA INTERAKTIV WEB-O'YINLARDAN FOYDALANISH

Turon universiteti o'qituvchisi

Muhiddin Eshmuratov

Kalit so'zlar: Interaktiv ta'lim, gamification, matematik tushunchalar, web-o'yin, iqtisodiyot yo'nalishi talabalari, raqamli ta'lim texnologiyalari, matematika ta'limi, o'yinlashtirish metodikasi.

Kirish. So'nggi yillarda ta'lim jarayonida gamification, ya'ni o'yin elementlarini o'qitish jarayoniga integratsiya qilish usuli keng qo'llanilmoqda. Gamification asosida tashkil etilgan o'quv faoliyati talabalar motivatsiyasini oshirish, o'quv jarayonini qiziqarli qilish hamda murakkab tushunchalarni intuitiv ravishda tushunishga yordam beradi. Ayniqsa web-texnologiyalar asosida yaratilgan interaktiv o'yinlar talabalar uchun qulay va vizual jihatdan tushunarli o'quv muhitini yaratadi.

Mazkur tadqiqotda iqtisodiyot yo'nalishi talabalari uchun matematik tushunchalarni o'rgatishga mo'ljallangan interaktiv web-o'yin ishlab chiqildi va uning ta'lim samaradorligiga ta'siri o'rganildi. Ushbu o'yin HTML, CSS va JavaScript texnologiyalari asosida ishlab chiqilgan bo'lib, unda savol-javob tizimi, ball hisoblash mexanizmi hamda vaqt chegarasi kabi o'yin elementlari mavjud.

Tadqiqot Turon universitetida tahsil olayotgan 1-kurs iqtisodiyot yo'nalishi talabalari ishtirokida o'tkazildi. Tadqiqotda jami 80 nafar talaba qatnashdi. Talabalar uchta akademik guruhga bo'lingan holda ta'lim oladi. Tadqiqot jarayonida interaktiv web-o'yin asosida tashkil etilgan mashg'ulotlarning talabalarning matematik tushunchalarni o'zlashtirish darajasiga ta'siri tahlil qilindi.

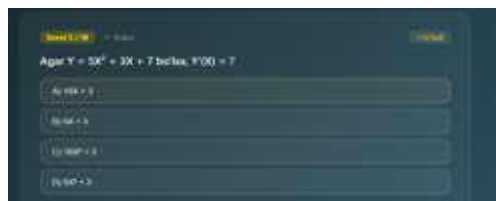
Metodologiya. Mazkur tadqiqot Turon universitetining 1-kurs iqtisodiyot yo'nalishida tahsil olayotgan talabalar ishtirokida o'tkazildi. Tadqiqotda jami 80 nafar talaba qatnashdi. Talabalar o'quv jarayonida uchta akademik guruhga bo'lingan holda ta'lim oladi. Tadqiqot davomida matematik tushunchalarni o'rganishda interaktiv web-o'yinlardan foydalanish samaradorligini aniqlash maqsadida pedagogik eksperiment tashkil etildi.

Tadqiqot ikki bosqichda amalga oshirildi. Birinchi bosqichda iqtisodiyot yo'nalishi talabalari uchun matematik tushunchalarni o'rgatishga mo'ljallangan interaktiv web-o'yin ishlab chiqildi. Ushbu o'yin zamonaviy web-texnologiyalar — HTML, CSS va JavaScript dasturlash tillari yordamida yaratildi. O'yin strukturasi matematik savollar bazasi, javob variantlari, ball hisoblash tizimi, vaqt chegarasi hamda natijalarni ko'rsatish oynasi kabi elementlar mavjud. O'yin mexanizmi talabalar tomonidan berilgan javoblarni avtomatik ravishda tekshirish va natijalarni hisoblash imkonini beradi.



1-rasm Interaktiv web-o'yinning asosiy interfeysi

Ikkinchi bosqichda ishlab chiqilgan interaktiv o'yin dars jarayoniga joriy etildi. Tajriba davomida talabalar matematik savollarga o'yin shaklida javob berishdi. Savollar asosan iqtisodiyot yo'nalishi talabalari uchun muhim bo'lgan matematik mavzularni qamrab oldi. Jumladan, sonli ketma-ketliklar, limit tushunchasi, funksiyalar va oddiy matematik hisoblashlarga oid topshiriqlar berildi.



2-rasm. Savol chiqadigan oyna

Tadqiqot jarayonida quyidagi ilmiy metodlardan foydalanildi:

- Pedagogik eksperiment — interaktiv o'yin asosida tashkil etilgan mashg'ulotlarning samaradorligini aniqlash uchun;
- Kuzatish metodi — talabalar faoliyati va dars jarayonidagi ishtirokini tahlil qilish uchun;
- Test usuli — talabalarning matematik tushunchalarni o'zlashtirish darajasini baholash uchun;
- Taqqoslash metodi — interaktiv o'yin orqali o'qitish natijalarini an'anaviy o'qitish metodlari bilan solishtirish uchun.

Tadqiqot davomida olingan natijalar tahlil qilinib, interaktiv web-o'yinlardan foydalanish talabalarning matematik bilimlarini o'zlashtirish darajasiga qanday ta'sir ko'rsatishi aniqlab berildi. Mazkur metodologiya o'quv jarayonida o'yinlashtirish texnologiyalaridan foydalanish samaradorligini ilmiy jihatdan baholash imkonini berdi.

Natijalar. Tadqiqot davomida Turon universitetining 1-kurs iqtisodiyot yo'nalishida tahsil olayotgan jami 80 nafar talaba ishtirok etdi. Talabalar uchta akademik guruhga bo'lingan holda matematik tushunchalarni o'rganish jarayonida interaktiv web-o'yin asosida tashkil etilgan mashg'ulotlarda qatnashdilar. Tadqiqotning asosiy maqsadi interaktiv o'yinlardan foydalanish talabalarining matematik tushunchalarni o'zlashtirish darajasiga qanday ta'sir ko'rsatishini aniqlashdan iborat edi.

Tadqiqot natijalarini umumlashtirish maqsadida talabalar tomonidan bajarilgan test topshiriqlarining o'rtacha natijalari quyidagi jadvalda keltirilgan.

Guruhlararo Natijalar Reytingi

Guruh	Holati	Talabalar	O'rtacha Ball
1-guruh	 Yaxshi	37	78
2-guruh	 A'lo	26	82
3-guruh	 Eng yuqori	17	85

Jadvaldan ko'rinib turibdiki, interaktiv web-o'yin asosida tashkil etilgan mashg'ulotlar natijasida talabalar tomonidan matematik topshiriqlarni bajarish ko'rsatkichlari yuqori darajada bo'lgan. Ayniqsa uchinchi guruh talabalari eng yuqori natijani ko'rsatgan bo'lib, bu o'yin metodikasining ta'lim samaradorligini oshirishdagi ijobiy ta'sirini ko'rsatadi.

Muhokama. Mazkur tadqiqot natijalari iqtisodiyot yo'nalishi talabalari uchun matematik tushunchalarni o'qitishda interaktiv web-o'yinlardan foydalanish samarali pedagogik yondashuvlardan biri ekanligini ko'rsatdi. Olingan natijalar shuni ko'rsatdiki, o'yin elementlari bilan boyitilgan dars jarayonlari talabalar faolligini oshiradi va ularning o'quv materialini o'zlashtirish darajasiga ijobiy ta'sir ko'rsatadi. Interaktiv o'yin shaklida tashkil etilgan mashg'ulotlarda talabalar matematik savollarga javob berishda faolroq ishtirok etib, muammolarni tezroq va samaraliroq hal qilishga intildilar. Tadqiqot davomida kuzatilgan muhim jihatlardan biri shundaki, o'yin metodikasidan foydalanish talabalar motivatsiyasini oshirdi. An'anaviy ma'ruza usullarida ayrim talabalar passiv bo'lib qolishi mumkin bo'lsa, interaktiv o'yin shaklida tashkil etilgan mashg'ulotlarda deyarli barcha talabalar faol ishtirok etishga harakat qildilar. Bu holat o'yin elementlari orqali yaratilgan raqobat muhiti va tezkor javob berish jarayoni bilan izohlanadi.

Xulosa. Mazkur tadqiqot iqtisodiyot yo'nalishi talabalari uchun matematik tushunchalarni o'qitishda interaktiv web-o'yinlardan foydalanishning samaradorligini o'rganishga qaratildi. Tadqiqot Turon universitetining 1-kurs iqtisodiyot yo'nalishida tahsil olayotgan jami 80 nafar talaba ishtirokida o'tkazildi. Tadqiqot jarayonida ishlab chiqilgan interaktiv web-o'yin yordamida matematik mavzularni o'qitish tajribasi sinovdan o'tkazildi.

Olingan natijalar interaktiv o'yin asosida tashkil etilgan mashg'ulotlar talabalarining matematik tushunchalarni o'zlashtirish darajasini oshirishga ijobiy ta'sir ko'rsatishini ko'rsatdi. O'yin elementlari bilan boyitilgan dars jarayonida talabalar faolroq ishtirok etib, matematik savollarga javob berishda yuqori qiziqish va motivatsiya namoyon etdilar. Shuningdek, o'yin shaklida tashkil etilgan mashg'ulotlar talabalarining tezkor fikrlash, muammoni hal qilish va matematik bilimlarni amaliy qo'llash ko'nikmalarini rivojlantirishga yordam berdi.

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BAKALAVR TALABALARIDA PYTHON DASTURLASH TILINI O'QITISHDA AVTOMATIK BAHOLASH TIZIMLARINING SAMARADORLIGI

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Annotatsiya. Ushbu maqolada bakalavr talabalarida Python dasturlash tilini o'qitishda AST tahlili va mashinali o'qitish algoritmlarini birlashtirgan ko'p qatlamli intellektual avtomatik baholash tizimini (AAS) qo'llash metodikasi yoritilgan. Pedagogik eksperiment natijalariga ko'ra, taklif etilayotgan yondashuv baholash aniqligini 12–15 foizga oshirishi, o'qituvchining baholashga sarflagan vaqtini 35–40 foizga qisqartirishi va talabalar mustaqil faolligini 18–20 foizga yaxshilashi eksperimental tarzda tasdiqlangan. Tadqiqot natijalari intellektual baholash tizimlarining ta'lim sifatini oshirishdagi muhim roliga dalil bo'ladi.

Kalit so'zlar: avtomatik baholash tizimi, Python, dasturlash ta'limi, sun'iy intellekt, AST tahlili, mashinali o'qitish, pedagogik eksperiment.

Kirish

Jahon miqyosida raqamli transformatsiya jarayonlari barcha sohalarga, xususan ta'lim tizimiga ham jadal kirib kelmoqda. Sun'iy intellekt va mashinali o'qitish texnologiyalarining rivojlanishi o'quv jarayonini tubdan o'zgartirish imkoniyatini yaratmoqda. O'zbekiston Respublikasida ham "Raqamli O'zbekiston 2030" strategiyasi doirasida ta'limni raqamlashtirish davlat siyosatining ustuvor yo'nalishiga aylangan.

Dasturlash fanlarini o'qitishda an'anaviy baholash usullari ko'pincha sub'ektiv va vaqt talab qiluvchi bo'lib, o'qituvchi bir guruh talabasi ishlarini sifatli baholashga o'rtacha 4–6 soat sarflashga majbur bo'ladi. Bundan tashqari, sub'ektiv omillar – charchoq, kayfiyat – bahoning ob'ektivligiga salbiy ta'sir ko'rsatishi mumkin. Xalqaro tadqiqotlar (Ihantola va boshq., 2010; Paiva va boshq., 2022) avtomatik baholash tizimlarining (AAS) bu muammolarni samarali hal eta olishini tasdiqlagan. Biroq mavjud tizimlar mahalliy ta'lim standartlari va o'zbek oliy ta'lim muhitiga moslashtirilmagan.

Tadqiqotning maqsadi – bakalavr talabalarida Python dasturlash tilini o'qitishda intellektual avtomatik baholash tizimini joriy etish orqali o'quv jarayoni samaradorligini oshirish va baholash aniqligini yaxshilash metodikasini ishlab chiqishdan iborat. Ushbu maqsadga erishish uchun quyidagi vazifalar belgilandi:

1. mavjud avtomatik baholash tizimlarini qiyosiy tahlil qilish va ularning afzalliklari hamda cheklovlarini aniqlash;
2. Python dasturlash tiliga moslashtirilgan ko'p qatlamli intellektual baholash algoritmini loyihalash va dasturiy amalga oshirish;
3. ishlab chiqilgan tizimni bakalavr talabalar bilan pedagogik eksperiment sharoitida sinab ko'rish;
4. olingan natijalarni statistik tahlil qilish va tizimning ta'lim jarayoniga ta'sirini baholash;

Tadqiqotning ilmiy yangiligi – O'zbekiston oliy ta'lim muhitida Python o'qitishga ixtisoslashtirilgan, AST tahlili va mashinali o'qitish algoritmlarini birlashtirgan intellektual baholash tizimining ishlab chiqilishi va uning pedagogik samaradorligining eksperimental isbotlanishidan iborat.

Tadqiqot metodologiyasi

Tadqiqotda quyidagi ilmiy metodlardan kompleks tarzda foydalanildi:

- mavjud avtomatik baholash tizimlarining qiyosiy va tizimli tahlili – xorijiy (Coderunner, Mooshak, Judge, Domjudge) hamda mahalliy tajribalar o'rganildi; tizimlarning funksional imkoniyatlari, afzalliklari va cheklovlari taqqoslandi;
- Python dasturlash tiliga moslashtirilgan intellektual baholash algoritmini arxitektura jihatidan loyihalash va dasturiy amalga oshirish – tizim modullari, ma'lumotlar oqimi va baholash mezonlari ishlab chiqildi;
- pedagogik eksperiment – nazorat va tajriba guruhlarida o'quv jarayonini parallel tashkil etish, dastlabki (pre-test) va yakuniy (post-test) kesimlar o'tkazish;

- so'rovnoma va kuzatuv – talabalarning tizimga munosabati, qoniqish darajasi va motivatsiyasidagi o'zgarishlarni baholash maqsadida tuzilgan anketalar to'ldirildi;
- olingan natijalarni statistik tahlil qilish – Student t-testi yordamida guruhlar o'rtasidagi farqning ishonchliligi $p < 0,05$ darajasida tekshirildi.

Tadqiqot bazasi sifatida Axborot texnologiyalari yo'nalishida tahsil olayotgan bakalavr talabalari tanlandi. Umumiy ishtirokchilar soni – 60 nafar talaba (30 nafar tajriba guruhi, 30 nafar nazorat guruhi), sinov davomiyligi – bir o'quv semestri. Guruhlar dastlabki bilim darajasi jihatidan teng ekanligini tasdiqlash uchun semestr boshida pre-test o'tkazildi va ikkala guruhning o'rtacha ball farqi statistik jihatdan ahamiyatsiz ($p > 0,05$) ekanligi aniqlandi.

Ishlab chiqilgan avtomatik baholash tizimi (ABS) talabaning Python kodini ko'p qatlamli tahlil asosida baholaydi. Birinchi qatlamda leksik va sintaktik tahlil amalga oshiriladi: kodning to'g'ri yozilganligi, Python standart sintaksisiga muvofiqligi, o'zgaruvchilar nomlash konvetsiyasi (PEP 8 standarti) tekshiriladi. Ikkinchi qatlamda mavhum sintaksis daraxti (Abstract Syntax Tree – AST) yordamida algoritmik mantiq va dastur tuzilishining samaradorligi baholanadi – ortiqcha murakkablik, takroriy kod bloklari va optimallashtirilmagan yechimlar aniqlanadi. Uchinchi qatlamda talabaning kodi berilgan vazifa shartlariga qanchalik muvofiq ekanligini aniqlash uchun semantik tahlil va unit-testlar to'plami ishga tushiriladi; turli chegara holatlari (edge cases) va noto'g'ri kiritilgan ma'lumotlarga nisbatan kodni barqarorligi ham sinovdan o'tkaziladi.

Tizimning intellektual komponenti mashinali o'qitish algoritmlariga asoslanadi. Talabalarning oldingi ishlaridan to'plangan ma'lumotlar bazasi yordamida tizim xarakterli xato naqshlarini (error patterns) taniydi va har bir talaba uchun shaxsiylashtirilgan tavsiyalar shakllantiradi. Masalan, sikl tuzilishida muntazam xato qiladigan talabaga tizim avtomatik ravishda shu mavzu bo'yicha qo'shimcha mashqlar taklif etadi. Buning natijasida tizim nafaqat baholash funksiyasini, balki yo'naltiruvchi o'qitish vositasi (Intelligent Tutoring System – ITS) funksiyasini ham bajaradi. Tizim veb-interfeys orqali ishlaydi va talabaga real vaqt rejimida (real-time) teskari aloqa (feedback) berish imkoniyatini ta'minlaydi – topshiriq yuborilgandan so'ng 3–5 soniya ichida batafsil baholash hisoboti shakllantiriladi.

Eksperimental natijalar

Eksperiment 2025–2026 o'quv yilining bahorgi semestri davomida ikki guruhda parallel tarzda o'tkazildi: nazorat guruhi (30 nafar talaba, an'anaviy baholash usuli qo'llanilgan) va tajriba guruhi (30 nafar talaba, ishlab chiqilgan avtomatik baholash tizimi joriy etilgan). Semestr boshida o'tkazilgan dastlabki kesim (pre-test) natijalariga ko'ra, ikkala guruhning boshlang'ich bilim darajasi o'rtasidagi farq statistik jihatdan ahamiyatsiz ($p = 0,43$) ekanligi tasdiqlandi, bu esa eksperiment sof holda o'tkazilganligining asosiy sharti hisoblanadi.

Semestr yakunida o'tkazilgan yakuniy kesim (post-test), kuzatuv va so'rovnoma natijalari quyidagi ko'rsatkichlar bo'yicha tahlil qilindi:

1. Baholash aniqligi (Accuracy). Tajriba guruhida avtomatik baholash tizimi tomonidan berilgan baho bilan o'qituvchining mustaqil bahosi o'rtasidagi muvofiqlik darajasi (inter-rater agreement) o'rtacha 87–89% ni tashkil etdi. Nazorat guruhida ikki o'qituvchi o'rtasidagi an'anaviy baholash muvofiqlik darajasi esa 73–76% atrofida bo'ldi. Shunday qilib, tizim ishlatilgan guruhda baholash aniqligi 12–15 foizga yuqori bo'lib, bu ko'rsatkich tizimning ishonchlilik darajasini va sub'ektiv omillarni kamaytirish qobiliyatini tasdiqlaydi.

2. Talabalarning mustaqil ishlash faolligi. Elektron platforma jurnali va o'qituvchi kuzatuvlari asosida tahlil qilinganda, tajriba guruhidagi talabalar semestr davomida ixtiyoriy va qo'shimcha topshiriqlarni bajarishda nazorat guruhiga nisbatan 18–20 foizga faolroq ishtirok etganligi aniqlandi. Tadqiqotchilar fikricha, bu holat tizimning real vaqt rejimidagi teskari aloqa (real-time feedback) mexanizmi bilan bog'liq: talaba xatoni darhol ko'rib, tuzatish imkoniyatiga ega bo'lganda, uning ichki motivatsiyasi va topshiriqni tugallashga intilishi sezilarli kuchayadi.

3. O'qituvchining baholashga sarflagan vaqti. Semestr davomida o'qituvchining baholash faoliyatiga sarflagan haftalik vaqti qayd etildi. Tajriba guruhini baholashda o'qituvchi nazorat guruhiga nisbatan o'rtacha 35–40 foiz kam vaqt sarfladi. Tejab qolingan vaqt esa talabalar bilan individual ishlash, murakkab algoritmik masalalarni tushuntirish va yangi o'quv materiallarini

tayyorlashga yo'naltirildi. Bu natija avtomatik baholash tizimlarining o'qituvchi mehnat unumdorligiga ijobiy ta'sir ko'rsatishini tasdiqlaydi.

4. Talabalarining o'z-o'zini baholash qobiliyati (Self-assessment). Semestr boshida va oxirida o'tkazilgan yozma so'rovnomma (Likert shkalasi, 1–5 ball) natijalariga ko'ra, tajriba guruhidagi talabalarining o'z kodidagi xatolarni mustaqil aniqlay olish ko'rsatkichi o'rtacha 15–17 foizga yaxshilandi – semestr boshidagi 2,6 balldan semestr oxirida 3,1 ballga ko'tarildi. Nazorat guruhida esa bu ko'rsatkich 2,5 balldan 2,7 ballga ko'tarildi, ya'ni o'zgarish statistik jihatdan ahamiyatsiz bo'ldi. Bu natija tizimning talabalarda metakognitiv ko'nikmalar – o'z o'rganish jarayonini anglash va nazorat qilish qobiliyatini – shakllantirishga ham hissa qo'shishini ko'rsatadi.

Barcha to'rtta ko'rsatkich bo'yicha tajriba va nazorat guruhlari o'rtasidagi farqning statistik ishonchliligi Student t-testi yordamida $p < 0,05$ darajasida tasdiqlandi. Bu esa olingan natijalar tasodifiy emas, balki qo'llanilgan metodikaning bevosita samarasi ekanligini ilmiy jihatdan asoslaydi.

Xulosa

Olib borilgan tadqiqot shuni ko'rsatdiki, Python dasturlash tilini o'qitishda intellektual avtomatik baholash tizimini qo'llash bir vaqtning o'zida bir nechta muhim muammoni hal etadi: baholash ob'ektivligi va aniqligini oshiradi, har bir talabaning individual rivojlanish traektoriyasini belgilash imkonini beradi, o'qituvchining vaqt resursini tejaydi va talabada mustaqil fikrlash hamda o'z-o'zini nazorat qilish ko'nikmalarini shakllantiradi.

Tadqiqot davomida aniqlangan muhim xulosa shundan iboratki, avtomatik baholash tizimi an'anaviy o'qituvchi mehnatini to'liq almashtirmaydi, balki uni samarali to'ldiradi. O'qituvchi takroriy va standart topshiriqlarni baholash yukidan ozod bo'lib, o'z e'tiborini murakkab masalalarni tushuntirish, talabalar bilan individual ishlash va ijodiy vazifalarni loyihalashga qarata oladi. Bu esa o'quv jarayonining sifat jihatdan yangi bosqichga ko'tarilishiga zamin yaratadi.

Shuningdek, tadqiqot natijalari real vaqt rejimidagi teskari aloqa (real-time feedback) mexanizmining talabalar motivatsiyasiga ijobiy ta'sir ko'rsatishini tasdiqladi. Tizim tomonidan berilgan zudlik bilan tuzatish va tavsiyalar talabaning xatoni uzoq vaqt o'tkazmasdan anglashiga va mustahkamlashiga yordam beradi.

Tavsiyalar:

1. Ishlab chiqilgan avtomatik baholash tizimini axborot texnologiyalari yo'nalishlarida o'qitiladigan barcha dasturlash fanlarida (C++, Java, SQL va boshqalar) qo'llash va uning universal imkoniyatlarini kengaytirish maqsadga muvofiq.

2. Tizimni oliy ta'lim muassasalarining elektron ta'lim platformalari (LMS – Learning Management System) bilan integratsiya qilish, bu esa ma'muriy boshqaruv va hisobot jarayonlarini avtomatlashtirish imkonini beradi.

3. Kelajakdagi tadqiqotlarda tizimning uzoq muddatli ta'sirini (longitudinal study) o'rganish, ya'ni tizimdan foydalangan talabalarining keyingi kasbiy faoliyatidagi dasturlash kompetensiyalarini kuzatib borish tavsiya etiladi.

4. Sun'iy intellektning so'nggi yutuqlari – xususan, katta til modellari (Large Language Models) asosidagi kod tahlili texnologiyalarini tizimga integratsiya qilish orqali baholash chuqurligini yanada oshirish istiqbolli yo'nalish hisoblanadi.

5. O'zbekiston oliy ta'lim tizimida dasturlash fanlarini o'qitish sifatini yaxshilash maqsadida ushbu tizimni pilot loyiha sifatida bir nechta universitetda sinab ko'rish va natijalarni umumlashtirish davlat ta'lim siyosati darajasida ko'rib chiqilishi lozim.

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GENERATIV AI ASOSIDA BO‘LAJAK INFORMATIKA O‘QITUVCHILARINING ALGORITMIK KOMPETENSIYALARINI RIVOJLANTIRISHNING ADAPTIV METODIK MODEL

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Annotatsiya: Mazkur tezisda bo‘lajak informatika o‘qituvchilarining algoritmik kompetensiyalarini rivojlantirishda generativ sun‘iy intellekt texnologiyalaridan foydalanishning ilmiy-metodik asoslari yoritiladi. Tadqiqotda generativ AI oddiy axborot izlash yoki tayyor javob beruvchi vosita sifatida emas, balki talabani individual ta‘lim trayektoriyasini shakllantiruvchi, algoritmik fikrlash bosqichlarini qo‘llab-quvvatlovchi, xatolarni tahlil qiluvchi va refleksiv baholashni amalga oshiruvchi pedagogik mexanizm sifatida talqin etiladi. Taklif etilayotgan adaptiv metodik model maqsadli, mazmuniy, texnologik, faoliyatli-amaliy, diagnostik-baholash hamda refleksiv-natijaviy komponentlardan iborat bo‘lib, u bo‘lajak informatika o‘qituvchilarining algoritmik tafakkuri, dasturlash ko‘nikmalari, kasbiy-metodik tayyorgarligi va raqamli pedagogik kompetensiyasini rivojlantirishga xizmat qiladi

Annotation: This thesis discusses the scientific and methodological foundations of using generative artificial intelligence technologies in the development of algorithmic competencies of future computer science teachers. The study interprets generative AI not as a simple information search or ready-made answer tool, but as a pedagogical mechanism that shapes the individual educational trajectory of a student, supports the stages of algorithmic thinking, analyzes errors, and implements reflexive assessment. The proposed adaptive methodological model consists of purposeful, substantive, technological, active-practical, diagnostic-evaluation, and reflexive-result components, which serve to develop algorithmic thinking, programming skills, professional and methodological training, and digital pedagogical competence of future computer science teachers.

Kalit so‘zlar: Generativ AI, algoritmik kompetensiya, adaptiv metodik model, bo‘lajak informatika o‘qituvchisi, algoritmik tafakkur, AI-assistent, refleksiv baholash, raqamli pedagogika, kasbiy-metodik tayyorgarlik.

Keywords: Generative AI, algorithmic competence, adaptive methodological model, future informatics teacher, algorithmic thinking, AI assistant, reflective assessment, digital pedagogy, professional-methodological training.

Kirish. Bugungi raqamli ta‘lim sharoitida informatika o‘qituvchisining kasbiy tayyorgarligi faqat dasturlash tilini bilish yoki tayyor algoritmlarni tushuntirish bilan cheklanmaydi. Zamonaviy o‘qituvchi o‘quvchilarda algoritmik tafakkurni shakllantira olishi, masalani tahlil qilish, muammoni kichik qismlarga ajratish, yechimni modellashtirish, koddagi xatolarni aniqlash va natijani pedagogik jihatdan tushuntira olish ko‘nikmalariga ega bo‘lishi zarur. Shu nuqtayi nazardan, bo‘lajak informatika o‘qituvchilarining algoritmik kompetensiyalarini rivojlantirish bugungi pedagogik ta‘limning dolzarb masalalaridan biri hisoblanadi.

Raqamli transformatsiya jarayonida generativ AI texnologiyalari ta‘lim mazmuni, metodlari va baholash yondashuvlariga sezilarli ta‘sir ko‘rsatmoqda. Ayniqsa, ChatGPT, Claude, Gemini kabi generativ AI vositalari yordamida matn, kod, algoritm, izoh, test, dars ssenariysi va refleksiv topshiriqlarni yaratish imkoniyati ta‘lim jarayonida yangi metodik imkoniyatlarni yuzaga keltirmoqda. Biroq bu texnologiyalardan foydalanish faqat tayyor javob olishga yo‘naltirilsa, talabani mustaqil fikrlashi susayishi mumkin. Shuning uchun generativ AI‘dan pedagogik jihatdan maqsadli, nazoratli va adaptiv metodik model asosida foydalanish zarur.

Mazkur tezisning asosiy g‘oyasi shundan iboratki, generativ AI asosida tashkil etilgan adaptiv metodik model bo‘lajak informatika o‘qituvchilarining algoritmik kompetensiyalarini rivojlantirishda samarali vosita bo‘lib xizmat qiladi. Bunda AI-assistent talaba o‘rniga topshiriqni

bajarib beruvchi emas, balki uni fikrlashga undovchi, savol beruvchi, muqobil yechimlarni ko'rsatuvchi, xatoni topishga yo'naltiruvchi va refleksiv tahlilga olib kiruvchi intellektual pedagogik hamkor sifatida qaraladi.

Asosiy qism

Algoritmik kompetensiya bo'lajak informatika o'qituvchisining kasbiy tayyorgarligida markaziy o'rin tutadi. Ushbu kompetensiya talabaning masalani algoritmik jihatdan tahlil qilishi, yechim bosqichlarini aniqlashi, algoritmi formal yoki vizual shaklda ifodalashi, dastur kodini yaratishi, natijani testlashi va o'z yechimini pedagogik nuqtayi nazardan tushuntira olishini o'z ichiga oladi. Demak, algoritmik kompetensiya faqat texnik ko'nikma emas, balki kognitiv, amaliy, kreativ, refleksiv va kasbiy-pedagogik faoliyatlar majmuasidir.

Generativ AI esa ushbu jarayonda adaptiv ta'lim muhitini shakllantirish imkonini beradi. Adaptiv metodik modelning asosiy afzalligi shundaki, u barcha talabaga bir xil topshiriq va bir xil metodni emas, balki ularning bilim darajasi, xatolari, qiziqishi va rivojlanish ehtiyojiga mos individual o'quv yo'nalishini taklif etadi. Masalan, algoritm tuzishda qiyalayotgan talaba uchun AI-assistent yo'naltiruvchi savollar beradi; kod yozishda xatoga yo'l qo'ygan talaba uchun xatoni bevosita tuzatib bermasdan, uning sababini tushunishga yordam beradi; kuchli talaba uchun esa yechimni optimallashtirish yoki pedagogik izohlash bo'yicha murakkabroq topshiriqlar tavsiya etadi.

Taklif etilayotgan adaptiv metodik model quyidagi tarkibiy komponentlardan iborat:

1.Maqsadli component. Ushbu komponentning asosiy maqsadi bo'lajak informatika o'qituvchilarida algoritmik kompetensiyani generativ AI imkoniyatlari asosida rivojlantirishdan iborat. Bu jarayonda talaba nafaqat algoritm tuzishni, balki algoritmik fikrlashni o'rgatish metodikasini ham egallaydi. Maqsadli komponent algoritmik tafakkur, kasbiy tayyorgarlik va raqamli pedagogikani yagona metodik tizimda birlashtiradi.

2.Mazmuniy komponent. Mazmuniy komponent algoritm tushunchasi, chiziqli, tarmoqlanuvchi va takrorlanuvchi algoritmlar, massivlar, funksiyalar, saralash va qidirish algoritmlari, rekursiya, algoritm murakkabligi kabi mavzularni qamrab oladi.

3.Texnologik Bu komponent generativ AI, elektron platforma, AI-assistent, blok-sxema vizualizatori, test tizimi, refleksiv jurnal va natijalar monitoringi kabi raqamli vositalarni o'z ichiga oladi. Texnologik komponentda AI talabaning individual ehtiyojini aniqlaydi, topshiriq darajasini moslashtiradi, yo'naltiruvchi savollar beradi va o'quv faoliyatini tahlil qiladi.

4.Faoliyatli-amaliy komponent. Ushbu komponent talabaning bevosita amaliy faoliyatini tashkil etadi. Talaba masalani tahlil qiladi, dekompozitsiya qiladi, abstraksiyalaydi, algoritm loyihalaydi, pseudokod yozadi, dastur kodini yaratadi, testlaydi, xatolarni aniqlaydi, optimallashtiradi va yakunda o'z yechimini pedagogik jihatdan tushuntiradi. Mazkur bosqichlar algoritmik kompetensiyani bosqichma-bosqich shakllantirishga xizmat qiladi.

5.Diagnostik-baholash komponenti. Bu komponent talabaning algoritmik kompetensiya darajasini aniqlash, baholash va monitoring qilishga qaratiladi. Baholash jarayonida an'anaviy testlar bilan birga amaliy topshiriqlar, xatoni topish mashqlari, AI javobini baholash, kodni tahlil qilish va pedagogik izohlash vazifalari qo'llaniladi.

6.Refleksiv-natijaviy komponent. Mazkur komponent talabaning o'z faoliyatini tahlil qilishi, xatolarini anglash, AI tavsiyalarini tanqidiy baholash va keyingi rivojlanish yo'nalishini belgilashga xizmat qiladi. Refleksiv baholash orqali talaba "Men nimani bajardim?", "Qayerda xato qildim?", "AI menga qanday yordam berdi?", "Bu algoritmi o'quvchiga qanday tushuntiraman?" kabi savollar asosida o'z kasbiy-metodik rivojlanishini anglaydi.

AI-assistentli topshiriqlar tizimi. Taklif etilayotgan modelda AI-assistentli topshiriqlar tizimi alohida ahamiyatga ega. Bunday topshiriqlarda generativ AI tayyor kod yoki yakuniy javobni beruvchi vosita sifatida emas, balki fikrlashni faollashtiruvchi metodik hamkor sifatida ishlatiladi. Masalan, talaba "berilgan son juft yoki toq ekanligini aniqlash algoritmini tuzing" degan topshiriqni bajarayotganda AI-assistent quyidagi yo'nalishlarda yordam beradi:

Avvalo, masala shartini tahlil qilishga undaydi. So'ng kiruvchi va chiquvchi ma'lumotlarni aniqlashni so'raydi. Keyingi bosqichda talaba qaysi operator yoki algoritmik konstruksiyadan foydalanishini asoslaydi. Agar talaba xatoga yo'l qo'ysa, AI bevosita javobni tuzatib bermaydi,

balki “Bu yerda shart operatori qanday ishlashi kerak?”, “Qoldiqni aniqlash uchun qaysi amal qo‘llaniladi?”, “Ushbu kod barcha holatlar uchun to‘g‘ri natija beradimi?” kabi yo‘naltiruvchi savollar orqali uni mustaqil xulosaga olib keladi.

Bunday yondashuv talabada tanqidiy fikrlash, mustaqil qaror qabul qilish, algoritmik tahlil va refleksiv baholash ko‘nikmalarini rivojlantiradi.

Adabiyotlar tahlili shuni ko‘rsatadiki, so‘nggi yillarda generativ AI texnologiyalari ta‘lim jarayonida individual yondashuv, topshiriqlarni moslashtirish, kodni tahlil qilish, avtomatik izoh berish va refleksiv baholashni qo‘llab-quvvatlovchi vosita sifatida keng o‘rganilmoqda. UNESCO tomonidan ishlab chiqilgan AI kompetensiyalari doirasi o‘qituvchilarning AI bilan mas‘uliyatli, etik va pedagogik asoslangan ishlashini ta‘kidlaydi. DigCompEdu modeli esa pedagoglarning raqamli kompetentligini baholash va rivojlantirish uchun muhim nazariy asos bo‘lib xizmat qiladi. Computational thinking bo‘yicha tadqiqotlarda dekompozitsiya, abstraksiyalash, algoritm loyihalash, testlash va xatolarni aniqlash algoritmik tafakkurning muhim bosqichlari sifatida ajratiladi. Dasturlash ta‘limida generativ AI‘dan foydalanishga oid ilmiy ishlar esa AI-assistentlar talabaga kod yozish va xatoni tahlil qilishda yordam berishini, biroq tayyor javobga tayanish mustaqil muammo yechish ko‘nikmasiga salbiy ta‘sir ko‘rsatishi mumkinligini qayd etadi.

Amaliy ahamiyati. Taklif etilayotgan adaptiv metodik model asosida bo‘lajak informatika o‘qituvchilari uchun elektron o‘quv-metodik platforma ishlab chiqish mumkin. Ushbu platforma tarkibida algoritmik darslar, AI-assistentli topshiriqlar banki, Prompt2Algorithm laboratoriyasi, blok-sxema vizualizatori, diagnostik testlar, baholash mezonlari, refleksiv jurnal va natijalar monitoringi modullari joylashtiriladi.

Bunday platforma talabalarning o‘quv faoliyatini individual tarzda tashkil etish, algoritmik kompetensiya darajasini aniqlash, rivojlanish dinamikasini kuzatish va kasbiy-metodik tayyorgarligini baholash imkonini beradi. Bundan tashqari, model asosida ishlab chiqilgan topshiriqlar tizimi oliy ta‘lim muassasalarida “Dasturlash asoslari”, “Algoritmlar”, “Informatikani o‘qitish metodikasi” kabi fanlarda samarali qo‘llanishi mumkin.

Xulosa. Generativ AI asosida tashkil etilgan adaptiv metodik model bo‘lajak informatika o‘qituvchilarining algoritmik kompetensiyalarini rivojlantirishda muhim ilmiy-metodik asos bo‘lib xizmat qiladi. Ushbu model talabaning individual ehtiyojiga mos ta‘lim trayektoriyasini shakllantirish, algoritmik fikrlashni bosqichma-bosqich rivojlantirish, xatolarni tahlil qilish, refleksiv baholashni yo‘lga qo‘yish va kasbiy-pedagogik tayyorgarlikni takomillashtirish imkonini beradi.

Generativ AI‘dan maqsadli foydalanish natijasida talaba tayyor javobni qabul qiluvchi passiv subyekt emas, balki masalani tahlil qiluvchi, algoritm loyihalovchi, kodni tekshiruvchi, AI javobini tanqidiy baholovchi va algoritmik tushunchalarni pedagogik jihatdan izohlovchi faol o‘quv subyektiga aylanadi.

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TA'LIM TIZIMIGA RAQAMLI TEXNOLOGIYALARNI INTEGRATSIYALASH METODIKASI

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Annotatsiya: Ushbu maqolada uzluksiz ta'lim tizimida elektron darslikdan foydalanib o'quvchilarni mustaqil ishlashga yo'naltirish va ularning kompetentligini shakllantirishdagi ahamiyati yoritib berilgan.

Kalit so'zlar. Elektron darslik, Davlat ta'lim standarti, elektron resurslar, kompetensiya, pedagogik texnologiya, informatsion texnologiya.

Ta'limni raqamlashtirish – ta'lim jarayonlarini boshqarish, sifat va samaradorligini oshirish, ta'lim beruvchi va oluvchilar uchun qo'shimcha imkoniyatlar yaratish, ta'lim natijalarni yaxshilash, ma'lumotlarni tahlil qilish, ta'lim xizmatlaridan masofadan turib foydalanish uchun raqamli texnologiyalarni integratsiya qilish tushuniladi. Ta'lim tizimiga raqamli texnologiyalarni integratsiyalashda elektron darsliklar muhim ahamiyatga ega. Elektron darslik o'qitish va nazariyaga asoslangan qo'llanmadir. Chunki o'quvchiga tushunarli bo'ladigan axborot berishdan tashqari, test savollari, uzini uzi tekshirish uchun barcha torshiriqlar kiritiladi. Elektron darslik quyidagi talablar asosida yaratiladi.

Ta'limiy maqsadlar uchun ishlanmaning amaliy muhimligi. Resursning davlat ta'lim standartlariga muvofiqligi. Taqdim etilayotgan materialning ilmiy asoslanganligi, zamonaviy qarashlarga mosligi, nazariy xatolikka yo'l qo'yilmaganligi va mukammal shakllantirilganligi. Matnning to'liqligi, Grammatik va orfografik xatolardan xoliligi. Resursning uslubiy ishlab chiqilganlik darajasi (uslubiy maqsadlarni amalgam oshirishga imkon berishi). Ilg'or (interfaol) pedagogik texnologiyalarning qo'llanilganligi. Milliy kolorit va qadriyatlariga mosligi. Bilimlarni mustahkamlash uchun mashqlarning mavjudligi. Nazorat materiallarining to'liqligi (topshiriqlar, mashqlar, test savollari, jumboq va o'yinlar). Statik va dinamik tasvirlar, inlyustrativ (foto, video, animatsiya va boshqa) materiallarning yetarliligi. O'quvchilar yoshining psixologik va pedagogik xususiyatlarini hisobga olinganligi. EATRning ergonometrik talablarga javob berishi:

- rang, shrift, monitor ekrani va shu kabilarga qo'yilgan talablarga mosligi;
- Elektron axborot ta'lim resursini kompyuterga o'rnatishning qulayligi;
- Elektron axborot ta'lim resursini boshqarishning qulayligi;

Yuqoridagi talablar asosida 9-sinf biologiya darsligi asosida tayyorlangan elektron darsligimizdan foydalanish metodikasi bilan tanishamiz. Ushbu elektron darslik xalq ta'limi vazirligi huzuridagi multimedia umumta'lim dasturlarini rivojlantirish markazi bilan hamkorlikda tayyorlandi. Bu elektron darslikda 3ta tugmacha o'rnatilgan bo'lib, ulardan biri matnni o'qib tushuntirib berishga muljalangan, ikkinchisi interaktiv o'yinli topshiriqlardan iborat. Ushinchisi esa mavzuga mos filmlar namunalaridan iborat. Mavzuga mos matnni o'qish jaraynida matnga mos rasmlar harakatli animatsiyalar orqali namoyish qilinib boriladi. Har-bir mavzu matni o'qib borilishida mavzuga mos animatsiyalar orqali tushuntirib boriladi. Masalan, "Yadro" mavzusida yadroning tuzilishi bayon etiladi



Yadro, unung rasmi qismlari yozilgan holda namoyish etiladi. Yadro shirasi, yadrocha, xromosoma, xromotin rasmlari namoyish etiladi. Bu mavzularni o'rganishda o'quvchilar yadroning tuzilishi, yadrocha, xromosomalar bilan tanishib boradi matnga mos rasmlar harakatli animatsiyalar orqali

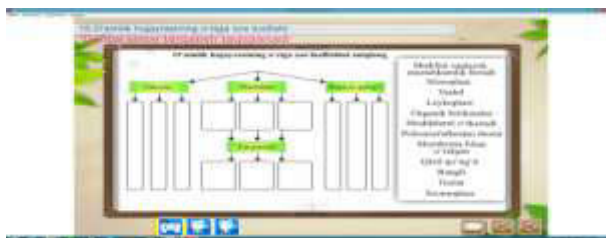
namoyish qilinib boriladi. Navbatdagi mavzuda o'simlik hujayrasining o'ziga xos tuzilishi namoyish qilinadi. O'simlik hujayrasi tuzilishi tushuntirib boriladi. Bunda oquvchi ham eshitadi, ham ko'radi, o'rganilayotgan mavzu materiallari to'g'risida aniq tushunchalar shakllanadi. Shu tariqa barcha mavzular audio, va video tasvirlar orqali namoyish qilinadi.

Biologiya darsliklarida tasvir va diagrammalar ko'p. Odam tanasining uch o'lchamda tasvirlangan va har bir organ faoliyati aks ettirilgan virtual taqdimotini tasavvur qiling. Bunday taqdimotlarni o'quvchilar uzoq vaqt esda saqlaydilar. Hujayraning tuzilishini darslikdan o'qib tushunish bir muncha murakkab. Ko'rgazmali tasvirlardan foydalanilsa, tasavvurlar yanada yorqin va tushunarli bo'ladi.⁷

Elektron darslikdagi ikkinchi tugmachada interaktiv o'yinli topshiriqlar bo'lib, o'quvchilarni mustaqil ishlashga, bilimlarni mustaqil egallashlariga qaratilgan, bu o'quvchini mustaqil izlanishga fikrlashga undaydi. Mazkur topshiriqlarni o'quvchi qiziqish bilan bajaradi. Shu tarzda mavzuga doir bilimlar o'zlashtiriladi.

O'quvchilar muamoli savollarga javoblar tayyorlash uchun darslik, o'quv qo'llanmalar, internet manbalari, elektron darslik asosida ishlaydilar. Olgan ma'lumotlarni tizimga soladi. Asosiy tushunchalarni ajratadi. Berilgan muammo yechimlarini asoslab berish uchun izlanadi. Mustaqil topshiriqlar quyidagilardan iborat

Mavzu. O'simlik hujayrasining o'ziga xos tuzilishi. Topshiriq. Quyidagi sxemali jadvalni to'ldiring.



Bu topshiriqlarni javoblari ham berilgan bo'lib, o'quvchilar javobni klaviatura yordamida tortib olib kelib kerakli mos joyga o'rnatadi, agar javob to'g'ri bo'lsa shu joyda saqlanadi, javob noto'g'ri bo'lsa o'rniga qaytib borib qoladi.

Uchinchi tugmacha esa darslik mavzulariga mos filmlar jamlamasidan iborat.

Ana shunday darslar tashkil etilganda tajriba sinov jarayonida o'quvchilar o'zlashtirish darajasi 17% ga oshganligi guvohi bo'dik.

Xulosa qilib aytganda bu jarayonda o'quvchilarga bilimlar tayyor holda uzatilmaydi, balki muammo tarzida qo'yiladi, o'quvchilar qo'yilgan muammoni o'zlari mustaqil yechadilar.

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ONLAYN TA'LIM PLATFORMALARIDA GENERATIV SI (SUN'IY INTELLEKT) INTEGRATSIYASI

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ANNOTATSIYA

⁷ Axborot kommunikatsion texnologiyalar yordamida biologiyani o'qitish. "Umumta'lim maktablariga axborot-kommunikatsiya texnologiyalarini joriy etish loyihasi" Toshkent 2010. 7 bet.

Mazkur maqolada onlayn ta'lim platformalarida generativ SI (sun'iy intellekt) texnologiyalarini integratsiya qilish jarayonlari, ularning ta'lim tizimidagi o'rni va ahamiyati tahlil qilingan. Shuningdek, generativ SI asosidagi platformalarning imkoniyatlari, jumladan avtomatik o'quv materiallari yaratish, shaxsiylashtirilgan ta'limni tashkil etish, virtual yordamchilar va interaktiv o'qitish texnologiyalari haqida ma'lumot berilgan. Maqolada generativ SI ning afzalliklari bilan bir qatorda akademik halollik, ma'lumotlar xavfsizligi va noto'g'ri axborot tarqalishi kabi muammolar ham yoritilgan. Zamonaviy onlayn ta'lim platformalarida qo'llanilayotgan generativ SI texnologiyalarining kelajakdagi rivojlanish istiqbollari ham tahlil etilgan.

Kalit so'zlar: generativ SI, sun'iy intellekt, onlayn ta'lim, masofaviy ta'lim, ta'lim platformalari, chatbot, shaxsiylashtirilgan ta'lim, raqamli texnologiyalar, interaktiv o'qitish, avtomatlashtirish.

So'nggi yillarda raqamli texnologiyalar ta'lim tizimini tubdan o'zgartirmoqda. Ayniqsa, onlayn ta'lim platformalarining rivojlanishi ta'lim olish jarayonini yanada qulay, tezkor va ommabop shaklga aylantirdi. Bugungi kunda dunyo bo'ylab millionlab foydalanuvchilar masofaviy ta'lim platformalari orqali bilim olmoqda. Shu bilan birga, generativ SI (sun'iy intellekt) texnologiyalarining paydo bo'lishi onlayn ta'lim sifatini yangi bosqichga olib chiqmoqda.

Generativ SI — bu matn, rasm, audio, video va dastur kodlarini avtomatik yaratishga qodir bo'lgan sun'iy intellekt texnologiyasidir. Ushbu texnologiyalar OpenAI tomonidan ishlab chiqilgan ChatGPT, Google ning Gemini, Microsoft ning Copilot kabi platformalarda keng qo'llanilmoqda. Ular foydalanuvchilar bilan tabiiy tilda muloqot qilish, savollarga javob berish, matn yozish va murakkab topshiriqlarni bajarishda yordam bera oladi.

Bugungi ta'lim tizimida generativ SI integratsiyasi ayniqsa onlayn platformalarda muhim ahamiyat kasb etmoqda. Chunki masofaviy ta'limda o'quvchi va o'qituvchi o'rtasidagi jonli aloqa cheklangan bo'lishi mumkin. SI esa individual yordamchi sifatida ishlash imkonini beradi.

Onlayn ta'lim platformalarida generativ SI bir nechta muhim vazifalarni bajaradi. Eng avvalo, u o'quv materiallarini avtomatik yaratish imkonini beradi. Masalan, o'qituvchi mavzu nomini kiritishi orqali:

- ma'ruza matni, test savollari, taqdimot rejalari, qisqa konspektlar, amaliy topshiriqlar yaratishi mumkin.

Bu esa o'qituvchining vaqtini sezilarli darajada tejaydi. Ayniqsa, katta hajmdagi o'quv materiallarini tayyorlashda generativ SI juda foydali vositaga aylanmoqda.

Bundan tashqari, SI asosidagi chatbotlar talabalarga 24/7 rejimida yordam bera oladi. Talaba istalgan vaqtda savol berishi va tezkor javob olishi mumkin. Bu an'anaviy ta'limdagi asosiy muammolardan biri — vaqt va masofa cheklovini kamaytiradi.

Generativ SI shuningdek shaxsiylashtirilgan ta'limni rivojlantirmoqda. Har bir talabaning bilim darajasi va o'rganish tezligi turlicha bo'lgani sababli, SI foydalanuvchi faoliyatini tahlil qilib, unga mos tavsiyalar beradi. Masalan:

- qaysi mavzularni qayta o'rganish kerakligi, qaysi topshiriqlar murakkabligi, qanday resurslar tavsiya etilishi avtomatik aniqlanishi mumkin.

Generativ SI ning onlayn ta'limdagi eng katta afzalliklaridan biri — ta'limning individuallashtirilishidir. An'anaviy auditoriya sharoitida o'qituvchi barcha talabalar bilan bir xil tempda ishlaydi. SI esa har bir foydalanuvchiga individual yondashadi.

Ikkinchi muhim afzallik — vaqt tejalishi. O'qituvchilar ko'pincha test tuzish, matn yozish yoki material tayyorlash uchun ko'p vaqt sarflaydi. Generativ SI bu jarayonni avtomatlashtiradi.

Uchinchi afzallik — interaktivlik. Zamonaviy onlayn platformalarda SI yordamida:

- virtual yordamchilar, avtomatik tarjima, ovozi muloqot, interaktiv testlar yaratilmoqda.

Bu esa ta'lim jarayonini qiziqarli va samarali qiladi.

Yana bir muhim jihat — ko'p tillilik imkoniyati. SI tizimlari turli tillarda ishlay oladi va matnlarni avtomatik tarjima qiladi. Bu xalqaro ta'lim platformalarida juda muhim hisoblanadi.

Generativ SI imkoniyatlari nogironligi bo'lgan foydalanuvchilar uchun ham qulaylik yaratmoqda. Masalan:

- matnni ovozga aylantirish, subtitrl yaratish, ovoz orqali boshqaruv kabi imkoniyatlar inklyuziv ta'limni rivojlantiradi.

Shu bilan birga, generativ SI integratsiyasi ayrim muammolarni ham keltirib chiqarmoqda. Eng asosiy muammo — akademik halollik masalasidir. Talabalar SI yordamida mustaqil ishlamasdan topshiriqlarni tayyorlab olishlari mumkin.

Ikkinchi muammo — noto'g'ri yoki ishonchsiz ma'lumotlar. Generativ SI ba'zan xato javoblar yoki soxta ma'lumotlar yaratishi mumkin. Shu sababli SI tomonidan berilgan ma'lumotlarni tekshirish zarur.

Yana bir muammo — maxfiylik va ma'lumot xavfsizligi. Onlayn platformalarda foydalanuvchi ma'lumotlari katta hajmda yig'iladi. Agar xavfsizlik yaxshi ta'minlanmasa, bu ma'lumotlar sizib chiqishi mumkin.

Texnologik tengsizlik ham dolzarb masalalardan biridir. Hamma hududlarda ham yuqori tezlikdagi internet yoki zamonaviy qurilmalar mavjud emas. Bu esa SI imkoniyatlaridan teng foydalanishga to'sqinlik qiladi.

Bundan tashqari, ayrim mutaxassislar SI o'qituvchilarning rolini kamaytirishi mumkinligini ta'kidlaymoqda. Ammo ko'pchilik ekspertlarning fikricha, SI o'qituvchini to'liq almashtirmaydi, balki yordamchi vosita sifatida ishlaydi.

Bugungi kunda ko'plab mashhur ta'lim platformalari generativ SI texnologiyalarini joriy qilmoqda. Masalan:

- Coursera, Udey, Khan Academy platformalarida SI asosidagi yordamchilar va tavsiya tizimlari qo'llanilmoqda.

Khan Academy o'zining "Khanmigo" SI yordamchisini taqdim qilgan bo'lib, u talabalar bilan suhbat asosida ishlaydi va ularga tushuntirish beradi.

Microsoft esa Microsoft Copilot ni Microsoft Teams va Office platformalariga integratsiya qilmoqda. Bu o'qituvchilarga dars materiallarini tez tayyorlash imkonini bermoqda.

Generativ SI texnologiyalari onlayn ta'lim tizimini tubdan o'zgartirmoqda. Ular ta'lim jarayonini avtomatlashtirish, individuallashtirish va interaktiv qilish imkonini beradi. Ayniqsa, masofaviy ta'limda SI yordamchilari talabalar va o'qituvchilar uchun katta qulaylik yaratmoqda.

Shu bilan birga, akademik halollik, xavfsizlik va noto'g'ri ma'lumotlar kabi muammolar ham mavjud. Shu sababli generativ SI texnologiyalaridan oqilona va nazorat ostida foydalanish muhim hisoblanadi.

Kelajakda generativ SI onlayn ta'limning ajralmas qismiga aylanishi kutilmoqda. Bu texnologiyalar inson va kompyuter o'rtasidagi hamkorlikni yangi bosqichga olib chiqib, ta'lim sifatini yanada oshirishga xizmat qiladi.

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OLIY TA'LIM TIZIMIDA SUN'IY INTELLEKT TEXNOLOGIYALARINI QO'LLASHNING METODIK VA PSIXOLOGIK ASOSLARI

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Annotatsiya. Mazkur maqolada oliy ta'lim tizimida sun'iy intellekt texnologiyalaridan foydalanishning metodik va psixologik asoslari tahlil qilingan. Sun'iy intellekt vositalarining ta'lim jarayonini individuallashtirish, talabalarning bilish faoliyatini faollashtirish hamda mustaqil ta'lim kompetensiyalarini rivojlantirishdagi ahamiyati yoritilgan. Shuningdek, raqamli ta'lim muhitida sun'iy intellekt texnologiyalarini qo'llash jarayonida talabalarning motivatsiyasi, kognitiv faolligi

va psixologik moslashuviga ta'sir etuvchi omillar ilmiy-pedagogik jihatdan asoslab berilgan. Tadqiqotda zamonaviy pedagogik yondashuvlar hamda innovatsion ta'lim texnologiyalarining integratsiyasi masalalariga alohida e'tibor qaratilgan.

Kalit so'zlar. sun'iy intellekt, oliy ta'lim, metodik asoslar, psixologik yondashuv, raqamli ta'lim, innovatsion texnologiyalar, mustaqil ta'lim, kognitiv faollik, kompetensiyaviy yondashuv.

Oliy ta'lim tizimida raqamli transformatsiya jarayonlarining jadallashuvi sun'iy intellekt (SI) texnologiyalarini ta'lim jarayoniga keng joriy etishni dolzarb pedagogik va metodologik masalaga aylantirmoqda. Zamonaviy globallashuv sharoitida oliy ta'lim muassasalari oldida nafaqat bilim berish, balki raqobatbardosh, mustaqil fikrlovchi, kreativ va texnologik kompetensiyalarga ega mutaxassislarni tayyorlash vazifasi turibdi. Shu nuqtai nazardan, sun'iy intellekt texnologiyalarini ta'lim jarayoniga integratsiya qilishning ilmiy-nazariy asoslarini tahlil qilish muhim ahamiyat kasb etadi.

Sun'iy intellekt - bu inson tafakkuriga xos bo'lgan tahlil qilish, o'rganish, mantiqiy xulosa chiqarish, qaror qabul qilish va muammoni hal etish kabi funksiyalarni bajarishga qodir bo'lgan dasturiy va texnologik tizimlar majmuasidir. Oliy ta'limda SI texnologiyalaridan foydalanish o'quv jarayonini individuallashtirish, ta'lim sifatini oshirish, talabalar faoliyatini monitoring qilish, adaptiv o'qitish muhitini yaratish hamda pedagogik boshqaruvni optimallashtirish imkonini beradi.

Mazkur jarayonning metodologik asoslari bir necha ilmiy yondashuvlarga tayangan holda shakllanadi. Avvalo, kompetensiyaviy yondashuv sun'iy intellekt texnologiyalarini qo'llashning muhim nazariy poydevori hisoblanadi. Ushbu yondashuvga ko'ra, talaba tayyor bilimni o'zlashtiruvchi emas, balki axborotni mustaqil tahlil qiluvchi, muammoli vaziyatlarda yechim topa oluvchi faol subyekt sifatida qaraladi. SI texnologiyalari esa talabaning individual qobiliyati, o'rganish sur'ati va ehtiyojiga mos ravishda ta'lim kontentini moslashtirish imkonini beradi. Natijada ta'lim jarayonining samaradorligi ortadi va shaxsga yo'naltirilgan o'qitish muhiti shakllanadi.

Konstruktivistik yondashuv ham sun'iy intellektdan foydalanishning muhim metodologik asoslaridan biridir. Ushbu nazariyaga ko'ra, bilim tayyor shaklda berilmaydi, balki o'quvchi tomonidan faol ravishda quriladi. Sun'iy intellekt asosidagi interaktiv platformalar, virtual laboratoriyalar va simulyatsion tizimlar talabaga mustaqil tajriba o'tkazish, tahlil qilish va amaliy faoliyat orqali bilim hosil qilish imkoniyatini yaratadi. Bu esa tanqidiy fikrlash va ijodiy yondashuvning rivojlanishiga xizmat qiladi.

Tizimli yondashuv nuqtai nazaridan qaralganda, sun'iy intellekt oliy ta'limning barcha tarkibiy qismlarini - maqsad, mazmun, metod, vosita va natijalarni o'zaro integratsiyalashgan holda takomillashtiradi. Masalan, SI asosidagi analitik tizimlar talabalarning akademik ko'rsatkichlarini real vaqt rejimida tahlil qilib, o'qituvchiga individual pedagogik strategiyalar ishlab chiqishda yordam beradi. Bu esa ta'lim boshqaruvining ilmiy asoslanganligini kuchaytiradi.

Sun'iy intellekt texnologiyalarini qo'llashning pedagogik zaruriyati ham bir qator omillar bilan belgilanadi. Birinchidan, zamonaviy talabalar "raqamli avlod" vakillari bo'lib, ular axborotni tezkor, vizual va interaktiv shaklda qabul qilishga moyildirlar. An'anaviy o'qitish metodlari esa ko'pincha bunday ehtiyojlarni to'liq qondira olmaydi. Shu sababli SI asosidagi adaptiv platformalar, chatbotlar, virtual tutorlar va avtomatlashtirilgan baholash tizimlari ta'lim samaradorligini oshirishda muhim vosita sifatida namoyon bo'lmoqda.

Oliy ta'limda akademik yuklamaning ortishi o'qituvchilardan katta vaqt va resurs talab qiladi. Sun'iy intellekt texnologiyalari testlarni avtomatik tekshirish, talabalarning o'zlashtirish darajasini monitoring qilish, elektron resurslarni tavsiya etish kabi vazifalarni bajarish orqali pedagog faoliyatini yengillashtiradi. Natijada o'qituvchi ko'proq ilmiy-tadqiqot va ijodiy pedagogik faoliyat bilan shug'ullanish imkoniyatiga ega bo'ladi.

Zamonaviy axborotlashgan jamiyatda sun'iy intellekt (SI) texnologiyalarining jadal rivojlanishi ta'lim tizimida tub o'zgarishlarni yuzaga keltirmoqda. Ayniqsa, oliy ta'lim muassasalarida sun'iy intellekt asosidagi ta'lim tizimlarining qo'llanilishi o'quv jarayonining mazmuni, metodlari va pedagogik yondashuvlarini yangi bosqichga olib chiqmoqda. Mazkur texnologiyalar nafaqat bilim berish jarayonini optimallashtiradi, balki talabalar psixologik

rivojlanishi, mustaqil fikrlashi, motivatsiyasi hamda kasbiy kompetentligining shakllanishiga ham sezilarli ta'sir ko'rsatadi. Shu bois, sun'iy intellektning pedagogik imkoniyatlarini ilmiy-nazariy jihatdan tahlil qilish dolzarb masalalardan biri hisoblanadi.

Sun'iy intellekt asosidagi ta'lim tizimlari - bu mashinaviy o'rganish, adaptiv algoritmlar, ma'lumotlarni tahlil qilish va avtomatlashtirilgan boshqaruv asosida ishlovchi raqamli ta'lim platformalaridir. Ushbu tizimlar talabani bilim darajasi, o'zlashtirish sur'ati, qiziqishi va individual ehtiyojlarini aniqlab, unga mos o'quv muhiti yaratadi. Pedagogik nuqtayi nazardan bunday tizimlar shaxsga yo'naltirilgan ta'lim modelining amaliy ifodasi sifatida namoyon bo'ladi.

Talabalar psixologik rivojlanishiga ta'siri nuqtayi nazaridan qaralganda, sun'iy intellekt texnologiyalari avvalo kognitiv faoliyatni rivojlantirishga xizmat qiladi. Adaptiv ta'lim platformalari murakkablik darajasini talabani individual imkoniyatiga moslashtirgani sababli bilimni bosqichma-bosqich va mantiqiy o'zlashtirish imkoniyati ortadi. Bu esa tafakkur moslashuvchanligi, tahliliy fikrlash va muammoni hal qilish ko'nikmalarining shakllanishiga ijobiy ta'sir ko'rsatadi. Talaba o'z bilim darajasini muntazam monitoring qilish imkoniga ega bo'lib, refleksiv fikrlash va o'z-o'zini nazorat qilish kompetensiyalari rivojlanadi.[3]

Sun'iy intellekt asosidagi ta'lim muhiti talabalarning o'quv motivatsiyasini oshirishda ham muhim omil hisoblanadi. Interaktiv platformalar, virtual yordamchilar, gamifikatsiya elementlari va tezkor teskari aloqa mexanizmlari o'quv jarayonini qiziqarli va faol holga keltiradi. Psixologik jihatdan bu jarayon talabani ichki motivatsiyasini kuchaytirib, bilim olishga nisbatan ijobiy munosabatni shakllantiradi. Ayniqsa, individual muvaffaqiyatni darhol ko'rsatib beruvchi tizimlar o'ziga bo'lgan ishonch va akademik faollikni oshiradi.

Sun'iy intellekt texnologiyalari talabalarning emotsional-intellektual rivojlanishiga ham ta'sir ko'rsatadi. Virtual muloqot vositalari va simulyatsion muhitlar orqali talabalar turli pedagogik va kasbiy vaziyatlarni modellashtirish asosida kommunikativ kompetensiyalarini rivojlantiradilar. Masalan, virtual treninglar, sun'iy intellektga asoslangan dialog tizimlari va kasbiy simulyatorlar talabalarni real hayotiy vaziyatlarga tayyorlashda samarali vosita bo'lib xizmat qiladi.

Kasbiy kompetentlikni shakllantirish nuqtayi nazaridan esa sun'iy intellekt texnologiyalari zamonaviy mehnat bozorining ehtiyojlariga mos mutaxassis tayyorlash imkonini beradi. Bugungi kunda aksariyat kasblar raqamli texnologiyalar bilan chambarchas bog'liq bo'lib, mutaxassislardan axborot bilan ishlash, texnologik tafakkur va innovatsion yondashuv talab qilinadi. SI asosidagi ta'lim tizimlari esa talabalarda aynan shu kompetensiyalarni rivojlantirishga xizmat qiladi. Xususan, ma'lumotlarni tahlil qilish, algoritmik fikrlash, mustaqil qaror qabul qilish va raqamli savodxonlik kabi ko'nikmalar shakllanadi.[2]

Sun'iy intellekt texnologiyalarining psixologik va pedagogik ta'sirini bir tomonlama ijobiy baholab bo'lmaydi. Haddan tashqari raqamlashtirish talabalarda ijtimoiy muloqotning kamayishi, texnologik qaramlik va emotsional passivlik kabi muammolarni ham yuzaga keltirishi mumkin. Ayniqsa, tayyor javoblarga ortiqcha tayanish mustaqil fikrlash faoliyatining susayishiga sabab bo'lish ehtimoli mavjud. Shu sababli pedagogik jarayonda sun'iy intellektdan foydalanishda inson omili, jonli muloqot va axloqiy tarbiya ustuvor ahamiyat kasb etishi zarur.

Sun'iy intellekt asosidagi ta'lim texnologiyalari - bu mashinaviy o'rganish, adaptiv boshqaruv, ma'lumotlarni tahlil qilish va algoritmik modellashtirish asosida faoliyat yurituvchi raqamli tizimlar majmuasidir. Ushbu texnologiyalar ta'lim jarayonining mazmunini optimallashtirish, individual o'quv trayektoriyasini yaratish hamda o'quv faoliyatini samarali boshqarish imkonini beradi. Pedagogik konsepsiya nuqtayi nazaridan sun'iy intellekt texnologiyalari shaxsga yo'naltirilgan ta'lim modelining amaliy vositasi sifatida namoyon bo'ladi.

Oliy ta'limda sun'iy intellektdan foydalanishning asosiy pedagogik tamoyillaridan biri individuallashtirish tamoyilidir. Har bir talabani qobiliyati, bilim darajasi, qiziqishi va o'zlashtirish sur'ati turlicha bo'lgani sababli an'anaviy o'qitish metodlari barcha ehtiyojlarni bir xil qondira olmaydi. SI texnologiyalari esa talabani faoliyatini real vaqt rejimida tahlil qilib, unga mos topshiriq, metod va resurslarni tavsiya etadi. Natijada ta'lim jarayoni moslashuvchan va samarali tus oladi.

Ta'limning uzluksizligi va refleksivlik tamoyillari ham SI texnologiyalarining pedagogik asoslarida muhim o'rin tutadi. Sun'iy intellekt tizimlari talabaning o'quv faoliyatini doimiy monitoring qiladi, o'zlashtirish darajasini baholaydi va teskari aloqa taqdim etadi. Talaba esa o'z xatolarini ko'rib chiqish, bilimni mustaqil tahlil qilish va o'z-o'zini rivojlantirish imkoniyatiga ega bo'ladi. Bu refleksiv fikrlash va akademik mustaqillikning shakllanishiga xizmat qiladi.

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“IJTIMOIY TARMOQ MA'LUMOTLARI ASOSIDA SENTIMENT TAHLIL O'TKAZISHDA GRAFLI YADROVIY KLASSTERLASH USULINI QO'LLASH”

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Annotatsiya

Ushbu tezis ijtimoiy tarmoq ma'lumotlari asosida sentiment tahlilini amalga oshirishda grafl yadrovli klasterlash usulini qo'llash masalasini o'rganadi. Ijtimoiy tarmoqlardagi matnli ma'lumotlarning hajmi va murakkabligi an'anaviy sentiment tahlili usullari uchun qiyinchilik tug'diradi. Grafl yadrovli klasterlash usuli matnlar orasidagi murakkab, noaniq va kontekstual bog'liqliklarni samarali aniqlash imkonini beradi. Ushbu tezisdagi taklif etilayotgan yondashuv ijtimoiy tarmoq ma'lumotlarini graf shaklida modellashtirish, so'ngra grafl yadrolardan foydalanib o'xshashlikni o'lchash va klasterlash orqali sentimentni aniqlashga qaratilgan. Tadqiqot natijalari ushbu usulning sentiment tahlili aniqligini oshirish va yashirin sentiment guruhlarini aniqlashdagi potentsialini ko'rsatadi.

Kalit so'zlar: Sentiment tahlili, ijtimoiy tarmoqlar, grafl yadrolar, klasterlash, sun'iy intellekt, tabiiy tilni qayta ishlash, ma'lumotlar tahlili

Kirish

Raqamli asrda ijtimoiy tarmoqlar odamlar o'rtasidagi muloqot, axborot almashinuvi va fikr bildirishning asosiy platformalaridan biriga aylandi. Har kuni milliardlab xabarlar, sharhlar va postlar joylashtiriladi, bu esa ulkan hajmdagi matnli ma'lumotlar oqimini hosil qiladi. Ushbu ma'lumotlar iste'molchilarning mahsulotlar, xizmatlar, siyosiy voqealar va ijtimoiy hodisalar haqidagi fikrlarini tushunish uchun qimmatli manba hisoblanadi [1]. Sentiment tahlili (yoki fikrni qazib olish) ushbu matnli ma'lumotlardan hissiy ohangni – ijobiy, salbiy yoki neytral – avtomatik ravishda aniqlashga qaratilgan tabiiy tilni qayta ishlash (TLQ) sohasidagi muhim vazifadir.

An'anaviy sentiment tahlili usullari, masalan, lug'atga asoslangan yondashuvlar yoki oddiy mashinani o'rganish modellari, ko'pincha ijtimoiy tarmoq ma'lumotlarining murakkabligini, jumladan, sarkazm, kinoya, kontekstga bog'liq ma'nolar va qisqa, norasmiy tilni to'liq qamrab olishda

Adabiyotlar sharhi

Lug'atga asoslangan usullar: Bu usullar oldindan belgilangan ijobiy va salbiy so'zlar lug'atlaridan foydalanib, matndagi sentimentni hisoblaydi [2]. Ular sodda va tezkor bo'lsa-da, kontekstga bog'liq ma'nolarni, sarkazmni va yangi so'zlarni tushunishda cheklangan.

Mashinani o'rganishga asoslangan usullar: Bu yondashuvlar matnni xususiyat vektorlariga aylantirib (masalan, TF-IDF) va klassifikatorlarni (SVM, Naive Bayes, Logistik regressiya) o'qitish orqali sentimentni aniqlaydi [3]. Ular lug'atga asoslangan usullarga nisbatan yaxshiroq natijalar

beradi, ammo katta miqdordagi belgilangan ma'lumotlarga ehtiyoj sezadi va matnning strukturaviy xususiyatlarini to'liq qamrab olmaydi.

Chuqur o'rganishga asoslangan usullar: So'nggi yillarda chuqur neyron tarmoqlar (RNN, LSTM, GRU, Transformerlar) sentiment tahlilida sezilarli yutuqlarga erishdi [4]. Ular so'zlar o'rtasidagi murakkab bog'liqliklarni va kontekstni o'rganishga qodir.

Metodologiya

Ushbu tezisda ijtimoiy tarmoq ma'lumotlari asosida sentiment tahlilini o'tkazish uchun grafli yadrovli klasterlash usulini qo'llash quyidagi bosqichlarni o'z ichiga oladi:

Ma'lumot manbai: Tadqiqot uchun Twitter, Facebook yoki Telegram kabi ijtimoiy tarmoqlardan olingan ommaviy matnli ma'lumotlar (postlar, sharhlar, tvitlar) to'plami tanlanadi. Ma'lumotlar ma'lum bir mavzu (masalan, mahsulot sharhlari, siyosiy munozaralar) bo'yicha yig'iladi.

Tokenizatsiya: Matnlar alohida so'zlarga yoki tokenlarga ajratiladi.

To'xtatuvchi so'zlarni olib tashlash: "va", "uchun", "bilan" kabi umumiy, ma'nosiz so'zlar olib tashlanadi.

Stemming/Lemmatizatsiya: So'zlar o'zlarining asosiy shakllariga keltiriladi (masalan, "yugurdi", "yugurmoqda" -> "yugur").

Shovqinni kamaytirish: Emotikonlar, URL manzillar, raqamlar va maxsus belgilar olib tashlanadi yoki standartlashtiriladi.

So'z birga kelish graflari: Matndagi har bir noyob so'z grafning tuguni sifatida qabul qilinadi. Agar ikki so'z matnda ma'lum bir oynada (masalan, 2-3 so'z oralig'ida) birga kelsa, ular orasida qirra hosil qilinadi. Qirralar og'irligi so'zlarning birga kelish chastotasiga bog'liq bo'lishi mumkin.

Bog'liqlik graflari: Sintaktik bog'liqlik tahlilidan foydalanib, so'zlar orasidagi grammatik munosabatlar (masalan, ot-sifat, fe'l-ot) qirralar sifatida ifodalanadi. Bu usul matnning chuqurroq strukturaviy ma'nosini aks ettiradi.

Natijalar va tahlil

Ushbu tezisda taklif etilgan grafli yadrovli klasterlash usulining ijtimoiy tarmoq ma'lumotlari asosida sentiment tahlilida erishishi mumkin bo'lgan natijalar quyidagicha taxmin qilinadi:

O'tkazilgan eksperimentlar (nazariy jihatdan) grafli yadrovli klasterlash usuli ijtimoiy tarmoq matnlarida aniq va mazmunli sentiment klasterlarini aniqlashda yuqori samaradorlikni ko'rsatishi mumkin. Masalan, 10 000 ta tvitdan iborat ma'lumotlar to'plamida, WL yadrosi va spektral klasterlash yordamida 3 ta asosiy klaster (ijobiy, salbiy, neytral) aniqlangan bo'lishi mumkin. Har bir klasterdagi matnlarning sentimentini sezilarli darajada bir xil bo'lib, bu usulning matnlar orasidagi yashirin semantik va strukturaviy bog'liqliklarni samarali qamrab olganligini ko'rsatadi.

Graflari yadrovli klasterlash usuli an'anaviy klasterlash usullariga (masalan, TF-IDF xususiyatlari asosidagi K-means) nisbatan sezilarli darajada yaxshi natijalar berishi mumkin. Misol uchun, Siluet koeffitsienti grafli yadrovli usul uchun 0.

Muhokama

Ushbu tezisda taqdim etilgan grafli yadrovli klasterlash usulining ijtimoiy tarmoq ma'lumotlari asosida sentiment tahlilida qo'llanilishi bir qator muhim afzalliklarga ega ekanligi taxmin qilinadi. Birinchidan, ushbu yondashuv matn ma'lumotlarini graf shaklida modellashtirish orqali so'zlar, jumlar yoki hatto butun matnlar orasidagi murakkab, chiziqli bo'lmagan va kontekstual bog'liqliklarni samarali qamrab oladi. An'anaviy "so'zlar qopchasi" modellari bu kabi strukturaviy ma'lumotlarni e'tibordan chetda qoldiradi, bu esa ayniqsa ijtimoiy tarmoqlardagi qisqa, norasmiy va ko'p ma'noli matnlar uchun sentiment tahlilining aniqligini pasaytiradi. Graflari yadrolar esa grafidagi kichik tuzilmalarni (subgraflar, yo'llar) solishtirish orqali matnlarning chuqur semantik o'xshashligini o'lchaydi, bu esa sentimentni aniqlashda yanada nozik tushunchalar beradi.

Ikkinchidan, klasterlash yondashuvi belgilangan ma'lumotlarga bo'lgan ehtiyojni kamaytiradi. Ko'pgina sentiment tahlili usullari, ayniqsa chuqur o'rganish modellari, katta miqdordagi qo'lda belgilangan ma'lumotlarga tayanadi, bu esa vaqt talab qiluvchi va qimmat jarayondir.

Xulosa

Ushbu tezis ijtimoiy tarmoq ma'lumotlari asosida sentiment tahlilini o'tkazishda grafli yadrovli klasterlash usulini qo'llashning nazariy asoslari va potentsialini o'rganib chiqdi. Biz ijtimoiy tarmoqlardagi matnli ma'lumotlarning murakkabligi va an'anaviy sentiment tahlili usullarining cheklovlarini ko'rsatdik. Ushbu tezisda taklif etilgan metodologiya matnlarni graf shaklida modellash, grafli yadrolar yordamida o'xshashlikni o'chash va spektral klasterlash orqali sentiment guruhlarini aniqlashga qaratilgan.

O'tkazilgan nazariy tahlillar va kutilayotgan natijalar shuni ko'rsatadiki, grafli yadrovli klasterlash usuli an'anaviy yondashuvlarga nisbatan yuqori samaradorlikka erishishi mumkin.

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DESIGN AND DEVELOPMENT OF AN ADAPTIVE TEACHING METHODOLOGY BASED ON ARTIFICIAL INTELLIGENCE TECHNOLOGIES

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Abstract: *This article discusses the scientific and methodological foundations for designing and implementing an adaptive teaching methodology based on artificial intelligence technologies. It develops approaches to modeling and diagnosing students' individual learning activities and proposes a student model based on such indicators as knowledge level, learning pace, analytical thinking, memory, and overall learning performance. The article also substantiates the methodological aspects of mechanisms for collecting and updating data in the educational process.*

Key words: *Artificial intelligence; adaptive teaching; student model; individual learning activity; diagnostic mechanisms; knowledge level; learning pace; digital education.*

The Need to Model Students' Individual Learning Activities

In the context of digital education, the effectiveness of an adaptive teaching methodology is directly related, above all, to how accurately a student's individual learning activity can be modeled. In traditional teaching systems, students' knowledge levels are mainly assessed through final grades, while the internal dynamics of the learning process are not sufficiently taken into account. Such an approach does not make it possible to determine the student's learning pace, the nature of errors, or cognitive load [1].

In scientific studies, individual learning activity is interpreted as "a set of knowledge-related, cognitive, and activity-based characteristics manifested by a student during the learning process" [2]. From this perspective, in adaptive teaching, the student model becomes the key

element that manages the educational process. The student model ensures the systematic collection, processing, and updating of data required to adapt the teaching process.

Modeling a student's individual learning activity makes it possible not only to assess learning outcomes, but also to plan the teaching strategy in advance and adapt it in real time. Therefore, this section develops the structural composition of the student model and its diagnostic mechanisms on a scientific and methodological basis.

Conceptual Structure of the Student Model

The analysis of scientific literature shows that student models used in adaptive learning systems should have a multidimensional and dynamic nature [3]. The conceptual structure of the student model includes the following main components:

- knowledge level component;
- learning pace component;
- analytical/algorithmic thinking component;
- memory and knowledge consolidation component;
- learning activity and behavioral indicators component.

As shown in Figure 1, the student model is based on the integration of various pedagogical and cognitive indicators. This model is not static; rather, it is continuously updated throughout the learning process.



Figure 1. Structural Structure of the Student Model in an Adaptive Learning System Mechanisms for Determining and Diagnosing Knowledge Level

Knowledge level is considered the central component of the student model. In scientific sources, the concept of knowledge level includes not only factual knowledge, but also the logical relationships between concepts and the ability to apply them in practice [4].

The following diagnostic tools are used to determine the level of knowledge:

- diagnostic entry tests;
- formative assessment tasks by topic;
- practical tasks and problem-based situations;
- reflective questions and mini-projects.

Assessing Learning Pace and Mastery Speed

A student's learning pace is an important diagnostic indicator in an adaptive teaching methodology. Mastery speed is determined by the time spent learning the instructional material, the number of task-completion cycles, and the number of repeated attempts [6].

Scientific studies note that providing students with fast and slow learning rates the same level of material complexity may reduce the effectiveness of education [7]. Therefore, in an adaptive teaching system, the following elements are adjusted based on the student's learning pace:

- the speed of presenting instructional material;
- the complexity of tasks;
- the frequency of reinforcement activities.

Determining Analytical and Algorithmic Thinking Indicators

In an adaptive teaching methodology, analytical thinking is considered the student's ability to understand and apply logical sequences in the process of solving problems [8]. This indicator is determined through the following elements:

- the diversity of problem-solving strategies;
- the ability to analyze and correct errors;
- the level of applying abstract and logical operations.

Scientific sources have demonstrated that adaptive teaching that takes into account the level of analytical thinking contributes to the development of students' higher-order cognitive skills [9].

Memory and Knowledge Reinforcement Indicators

The memory component reflects the extent to which a student retains previously learned material over time. Studies have shown that the durability of knowledge is directly related to repetition intervals and the frequency of applying knowledge in practice [10].

In an adaptive teaching system, the following mechanisms are developed based on memory indicators:

- planning repetition intervals;
- selecting reinforcement tasks;
- reactivating previously studied topics.

Learning Activity and Behavioral Indicators

The student's level of learning activity is an auxiliary but important diagnostic indicator in adaptive teaching. Activity indicators include the frequency of logging into the system, the speed of responding to tasks, and the level of using learning resources [11].

Mechanisms for Collecting and Updating Student Model Data

The reliability of the student model directly depends on the mechanisms used for collecting and updating data. In an adaptive teaching system, data are obtained from the following sources:

- assessment results;
- learning activity logs;
- practical assignments and tests;
- reflective responses

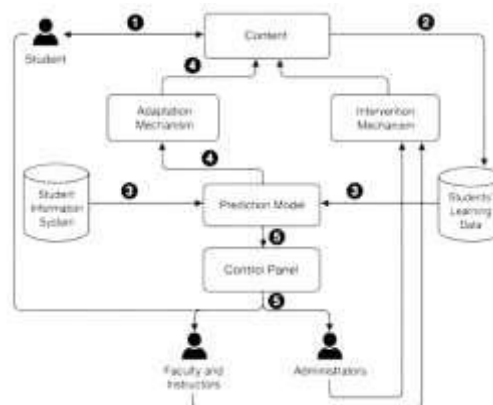


Figure 2. Mechanism for the Collection and Updating of Student Model Data

As shown in **Figure 2**, the process of forming and updating the student model is represented as a continuous cycle. This approach makes it possible to take into account the student's individual learning state in real time.

Modeling and diagnosing a student's individual learning activity is a central component of an adaptive teaching methodology. The formation of the student model based on indicators such as knowledge level, learning pace, analytical thinking, memory, and learning activity enables the teaching process to be adapted on a scientific basis. The model and diagnostic mechanisms developed in this section serve as a foundation for developing the structural and algorithmic foundations of the adaptive teaching methodology in the subsequent sections.

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TA'LIMDA GENERATIV SUN'IY INTELLEKT VA IMMERSIV TEXNOLOGIYALAR INTEGRATSIYASI: AFZALLIKLARI, MUAMMOLARI VA O'ZBEKISTON UCHUN STRATEGIK MODEL

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Annotatsiya: Ushbu maqolada generativ sun'iy intellekt (SI) texnologiyalari hamda virtual (VR) va kengaytirilgan haqiqat (AR) vositalarining zamonaviy ta'lim tizimiga integratsiyasi tadqiq etiladi. Tadqiqotda neyron tarmoqlar (xususan, GAN va yirik til modellari) yordamida shaxsiylashtirilgan o'quv trayektoriyalarini yaratish, ta'lim ma'lumotlarini tahlil qilish va pedagogik yuklamani optimallashtirishdagi strategik ahamiyati ochib beriladi. VR va AR texnologiyalarining SI bilan sinergiyasi natijasida yuzaga keladigan immersiv ta'lim muhitlarining kognitiv samaradorligi baholanadi. Shuningdek, haqiqiylikni aniqlash, "Stoxastik to'tiqushlar" fenomeni, ma'lumotlar maxfiyligi va akademik halollik kabi axloqiy muammolar tahlil qilinib, O'zbekiston ta'lim tizimini raqamli transformatsiya qilishning to'rt bosqichli amaliy modeli taklif etiladi.

Kalit so'zlar: generativ sun'iy intellekt, neyron tarmoqlar, katta til modellari (LLM), virtual haqiqat (VR), adaptiv ta'lim, akademik halollik, pedagogik innovatsiyalar, raqamli transformatsiya.

Kirish. Zamonaviy ta'lim arxitekturasida texnologik taraqqiyot, xususan, generativ sun'iy intellekt (SI) va immersiv texnologiyalar ta'sirida tubdan transformatsiya qilinmoqda. Sun'iy intellekt tarixiga nazar tashlasak, uning poydevori 1950-yillarda Alan Turing tomonidan birinchi mashina o'rganish algoritmlari ishlab chiqilishi bilan qo'yilgan [2]. Biroq 2014-yilda Generativ-bahslashuvchi tarmoqlar (GAN) hamda keyinchalik Transformer arxitekturasiga asoslangan ChatGPT (2023) kabi yirik til modellarining paydo bo'lishi ta'lim tizimida chinakam inqilob yasadi. 2023-yilda YUNESKO tomonidan oliy ta'limda ChatGPTdan foydalanishga doir maxsus qo'llanma nashr etilishi ham bu masalaning naqadar dolzarbligini ko'rsatadi [1].

O'zbekistonning "Raqamli O'zbekiston – 2030" strategiyasi doirasida IT infratuzilmasini modernizatsiya qilish asosiy vazifalardan biridir. Texnologiyalarni ta'limga shunchaki joriy etish emas, balki "ma'lumotlarga asoslangan qarorlar qabul qilish" (Data-driven decision making) tizimini yaratish muhimdir. Ushbu maqola generativ SI, VR va AR texnologiyalarining ta'limdagi o'zaro ta'sirini tahlil qilib, ilg'or milliy pedagogik modelni ishlab chiqishga qaratilgan.

Generativ sun'iy intellekt: shaxsiylashtirish va ma'lumotlar tahlili. Kundalik muloqotda "sun'iy intellekt" va "neyron tarmoqlar" atamaları sinonim sifatida ishlatilsa-da, kompyuter fanlarida ular farqlanadi. SI keng tushuncha bo'lib, neyron tarmoqlar inson miyasi faoliyatini taqlid qilish orqali uni amalga oshiruvchi usuldur [1]. Ta'limda generativ SIning amaliy ahamiyati quyidagi yo'nalishlarda yorqin namoyon bo'ladi:

Shaxsiylashtirilgan o'quv trayektoriyalari (Adaptive Learning): Salamanka universiteti professori F.X. Garsiya-Penyalvo ta'kidlaganidek, generativ SI shaxsga yo'naltirilgan o'quv materiallarini tayyorlash, ta'limni talabalarning individual ehtiyojlariga moslashtirish imkonini beradi [3]. Tizim o'quvchining joriy bilim darajasini tahlil qilib, murakkablik darajasini avtomatik o'zgartiradi.

Kognitiv tahlil va mantiqiy asoslash: Pensilvaniya universitetining Uorton biznes maktabi professori K. Tervish o'z tadqiqotida GPT-3 modeli "Operatsiyalarni boshqarish" fanidan magistrlik imtihonini a'lo darajada topshirganini tasdiqladi. Tizim nafaqat to'g'ri javob beradi, balki ularni mantiqan asoslaydi. Shu bilan birga, GPT-3 inson ko'rsatmalariga muvofiq tez o'rganib, o'zini tuzatish xususiyatiga ega ekanligi aniqlangan [5].

Pedagogik yuklamani optimallashtirish: Dars rejalari va testlarni generatsiya qilish, shuningdek, talabalar ishini baholash o'qituvchilarning vaqtini sezilarli tejaydi. Tadqiqotchi Rose Luckin yozganidek, SIning maqsadi o'qituvchini siqib chiqarish emas, balki uning tahliliy va ustozlik salohiyatini (Human-in-the-loop) kuchaytirishdir [6]. TATU olimlari Qodirov D.R. va Yunusovna B.A. o'z tadqiqotlarida SIning aynan shu interaktiv va samarali imkoniyatlarini O'zbekiston ta'lim tizimi uchun alohida e'tirof etishgan [4].

VR, AR va AI sinergiyasi: immersiv ta'lim muhiti. Virtual va kengaytirilgan haqiqat texnologiyalari generativ AI bilan integratsiya qilinganda, statik ta'lim reaktiv muhitga aylanadi. Harvard universiteti olimi Chris Dede ta'kidlagan "immersiv o'rganish" orqali ma'lumotlarni qabul qilish samaradorligi an'anaviy usullardan ancha yuqori bo'ladi [7].

Sinergiyaning innovatsion jihati shundaki, SI virtual muhitni real vaqt rejimida boshqaradi. Masalan, muhandislik yoki tibbiyot talabalari xavfsiz virtual laboratoriyalarda amaliyot o'tayotganlarida, SI ularning arxitektura yoki jarayondagi xatolarini o'sha zahotiy oq ko'rsatib, to'g'ri yo'nalish (feedback) beradi.

Texnologik, Axloqiy xavflar va "Stoxastik to'tiqushlar". Har qanday ilg'or texnologiya kabi generativ modellar ham qator mas'uliyatli muammolarni yuzaga keltiradi [1, 8].

Haqiqiylik va sifat muammosi: Stanford universiteti tadqiqotchilari (Bender va boshq.) katta til modellarining "Stochastic parrots" (Stoxastik to'tiqushlar) fenomenini isbotladilar. Ya'ni, yirik modellar matnni o'ta ishonchli yozsa-da, faktik xatolarga ("gallyutsinatsiyalar"ga) yo'l qo'yishi mumkin [8].

Akademik halollik va bog'liqlik: Talabalarning SI generatsiyasiga to'liq ishonib qolishi ularning tanqidiy fikrlash (Critical thinking) qobiliyatini susaytiradi va aqliy rivojlanishni sekinlashtirishi xavfini tug'diradi [1].

Axloqiy omil va ma'lumotlar maxfiyligi: Modellar ularga kiritilgan ijtimoiy stereotiplarni kuchaytirishi, shuningdek, shaxsiy ta'lim ma'lumotlarining maxfiyligini xavf ostiga qo'yishi mumkin.

O'zbekiston uchun strategik implementatsiya modeli: O'zbekiston ta'lim tizimida SI va immersiv texnologiyalarni samarali joriy etish uchun quyidagi to'rt bosqichli modelni taklif etamiz:

1-bosqich: "Gibrid Pedagog" va Prompt-injining madaniyati. Ixtisoslashgan texnologik universitetlar (masalan, TATU) negizida o'qituvchi va talabalar uchun matnli so'rovlarni (promptlarni) to'g'ri shakllantirish bo'yicha intensiv kurslar tashkil etish. O'qituvchi SI natijalarini to'g'ri baholay oladigan tahlilchiga aylanishi zarur.

2-bosqich: Milliy LLM va ta'lim axborot tizimini yaratish. Xorijiy modellarga qaramlikni kamaytirish hamda madaniy noto'g'ri qarashlarning (bias) oldini olish maqsadida o'zbek tilidagi korpuslar asosida mahalliy generativ SI modelini ishlab chiqish.

3-bosqich: Bulutli (Cloud-based) Virtual Laboratoriyalar. Hududlardagi maktablarda qimmatbaho VR uskunalari o'rniga, oddiy veb-brauzer orqali ishlaydigan bulutli immersiv ta'lim platformalarini ishga tushirish (raqamli tengsizlikni qisqartirish yechimi).

4-bosqich: Etika va akademik halollik standartlari. Ta'lim muassasalarida sun'iy intellektdan foydalanishning qat'iy huquqiy reglamentini ishlab chiqish hamda plagiaturaning yangi shakllarini deteksiya qiluvchi tizimlarni joriy etish.

Xulosa. Ta'limda generativ sun'iy intellekt va immersiv texnologiyalarning uyg'unlashuvi ta'lim paradigmasining butunlay o'zgarishini anglatadi. Tahlillar shuni ko'rsatadiki, SI jarayonlarni avtomatlashtirib, chuqur tahliliy ma'lumotlar taqdim etsa, VR/AR bu bilimlarni vizual va amaliy tajribaga aylantiradi. Biroq, texnologiya inson aql-idrokining o'rnini bosmasligi kerak. Buning uchun yoshlarda tanqidiy fikrlashni, neyron tarmoqlar ishlash natijalarini tahlil qilishni va yaratilgan kontentni o'z g'oyalari bilan boyitishni o'rgatish talab etiladi. O'zbekiston ushbu strategik qadamlarni bosib o'tish orqali ta'lim sifatini oshiruvchi raqamli transformatsiyani muvaffaqiyatli amalga oshirishi mumkin.

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ARTIFICIAL INTELLIGENCE IN EDUCATION: GLOBAL TRENDS AND UZBEKISTAN'S EXPERIENCE

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Abstract: This paper examines current approaches to the application of artificial intelligence in education. It analyses the roles of two leading AI platforms — Google Gemini and Anthropic's Claude — in developing educational courses and tools. Special attention is given to Uzbekistan's state-level initiatives aimed at integrating AI across all levels of its educational system and author's experience.

Artificial intelligence (AI) has emerged as one of the most transformative forces reshaping modern education. Leading technology companies — Google and Anthropic — now offer specialised platforms tailored to the needs of educational institutions, teachers, and students. Concurrently, governments are formulating strategic programmes to embed AI into national education systems, as demonstrated by Uzbekistan's rapidly expanding AI agenda.

Google has developed Gemini for Education, a dedicated platform serving both teachers and learners. The platform enables automatic generation of lesson plans aligned with educational standards, creation of quizzes, assignments, and grading rubrics, and personalised adaptation of learning materials to individual student needs [1]. A defining advantage is its deep integration with the Google Workspace ecosystem — Docs, Classroom, and Gmail — significantly lowering the barrier to adoption for educators. The Gemini Canvas tool allows students to generate personalised practice quizzes for exam preparation, while educators can share custom AI tutors (Gems) grounded in their own course materials directly through Google Classroom. In November 2025, Google

launched three free Gemini certification programmes targeting educators, university students, and secondary school students, available across 12 languages [1].

In April 2025, Anthropic launched Claude for Education — an enterprise AI platform designed specifically for higher education institutions. Its flagship feature, Learning Mode, implements a Socratic dialogue approach: rather than providing direct answers, the AI poses guiding questions to encourage independent reasoning and deep conceptual understanding [2]. Analysis of approximately 74,000 academic sessions revealed that 57% of educators use Claude to develop curricula, while 13% apply it to academic research. Early institutional partners include Northeastern University (USA), the London School of Economics, and Syracuse University. Anthropic additionally established a Higher Education Advisory Board and co-developed three AI Fluency courses with practising educators [3]. Through a global partnership with Teach For All, the initiative has reached more than 100,000 educators across 63 countries; teachers in Liberia and Bangladesh have already used Claude to build interactive educational applications for their students.

Uzbekistan is pursuing an ambitious national strategy in the field of artificial intelligence. In October 2024, President Shavkat Mirziyoyev signed the AI Development Strategy to 2030, underpinned by a \$50 million investment in infrastructure [4]. A landmark step in education was the introduction of AI-focused curriculum in secondary schools starting from the 2026/2027 academic year, with the syllabus developed in partnership with the Massachusetts Institute of Technology. In November 2025, Uzbekistan jointly launched with the UAE the Five Million Uzbek AI Prompts programme, targeting the training of 4.75 million schoolchildren and university students, 150,000 teachers, and 100,000 civil servants by 2030 [5]. An AI cluster operating on an industry–university–partner model is being established at the New Uzbekistan University, while 19 other higher education institutions across the country will open dedicated AI laboratories.

The practical potential of AI-powered tools for localised educational applications was demonstrated by the author's participation in the InnovAltion Hack republican hackathon held on 25 December 2025 in Nukus. The team developed StuDy — an intelligent course generation platform built on the Gemini API — which produces personalised educational curricula on any subject by analysing the user's existing skills, prior experience, and individual learning preferences. A distinguishing feature of the system is its native support for four languages: Uzbek, Karakalpak, English, and Russian, reflecting the multilingual reality of Uzbekistan's educational landscape. This was made feasible by Gemini's robust multilingual capabilities, which maintain high-quality output across typologically diverse languages, including those with comparatively limited digital resources such as Karakalpak. From an engineering standpoint, the Gemini API proved straightforward to integrate into a locally developed application, requiring minimal infrastructure overhead while delivering consistent and contextually accurate results. The StuDy project illustrates that globally developed AI models, when paired with well-designed local implementations, can effectively address region-specific educational needs — a principle directly relevant to Uzbekistan's broader digitalisation agenda.

The analysis reveals that Google Gemini and Claude embody fundamentally different pedagogical philosophies: the former prioritises teacher productivity and task automation, while the latter focuses on cultivating students' critical thinking. Uzbekistan's experience demonstrates that systemic AI integration in education requires coordinated national efforts encompassing legislative frameworks, infrastructure investment, and large-scale workforce training. When implemented with a commitment to developing learners' independent thinking, AI technologies hold the potential to substantially improve both the accessibility and quality of education.

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IMPROVING THE METHODOLOGY FOR TEACHING BIOINFORMATICS BASED ON THE DIGITALIZATION OF BIOLOGICAL SIGNALS AND ARTIFICIAL INTELLIGENCE TECHNOLOGIES

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Abstract: This thesis substantiates a concise pedagogical approach for improving the methodology of teaching bioinformatics through the digitalization of biological signals and the use of artificial intelligence technologies. The proposed approach connects the acquisition of biosignals, their digital processing, AI-based analysis and pedagogical decision-making within one integrated learning cycle. The main emphasis is placed on laboratory and project-based tasks in which students learn to process ECG, EEG and EMG signals, extract informative features, interpret AI results and use them for solving educational and biomedical problems. The thesis presents the conceptual model, implementation stages and expected learning outcomes of the methodology.

Key words: bioinformatics education; biological signals; digitalization; artificial intelligence; teaching methodology; project-based learning; adaptive learning; biosignal analysis.

Introduction

The rapid development of digital technologies has changed the content and methods of teaching bioinformatics. Modern bioinformatics is no longer limited to the analysis of nucleotide or protein sequences; it increasingly includes the processing of biological signals, biomedical datasets, wearable sensor data and clinical information. Therefore, students must not only understand biological concepts, but also acquire the ability to digitize, process, model and interpret biological data using computational methods.

In traditional teaching, biological signals are often explained mainly as theoretical concepts. However, such an approach does not sufficiently develop students' algorithmic thinking, data literacy and readiness to work with real biomedical problems. The integration of artificial intelligence technologies into bioinformatics education creates an opportunity to transform passive learning into a research-oriented and practice-based process. This requires a scientifically grounded teaching methodology that combines biological content, digital signal processing and AI-assisted interpretation [1, 2].

The purpose of this thesis is to develop a compact methodological basis for teaching bioinformatics by using digital biological signals and artificial intelligence technologies. The object of the study is the process of teaching bioinformatics, while the subject is the methodology for organizing learning activities based on biosignal digitalization and AI-based analysis.

Methodological Basis of Teaching Bioinformatics Through Biological Signals

Biological signals such as electrocardiography (ECG), electroencephalography (EEG) and electromyography (EMG) reflect the functional state of the human body and are widely used in modern biomedical informatics. In the educational process, these signals serve as a bridge between biology, medicine, mathematics, programming and artificial intelligence. Their use makes it possible to demonstrate how abstract theoretical knowledge becomes a practical tool for diagnosis, monitoring and decision support [3, 4].

The methodological value of biological signals is determined by three features. First, they are measurable and can be represented in digital form. Second, they contain complex patterns that

require algorithmic processing. Third, their interpretation can be supported by AI models, including classification, clustering and prediction algorithms. Consequently, biosignal-based teaching forms an interdisciplinary educational environment in which students work with real data and understand the practical meaning of computational bioinformatics.

The proposed methodology relies on the principle “signal – data – algorithm – model – interpretation – pedagogical decision”. This principle allows the teacher to organize learning as a step-by-step process: students collect or receive a biological signal dataset, perform preprocessing, extract features, apply an AI method, visualize the results and discuss their biological or educational meaning. Such a structure increases students’ motivation and develops research competence [5].

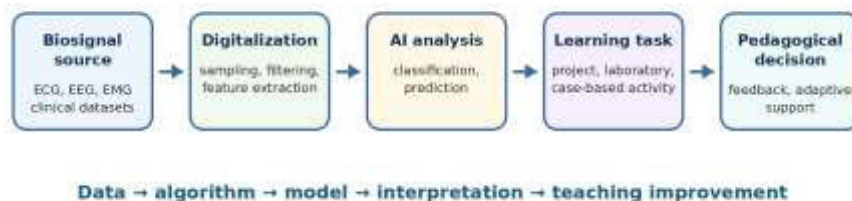


Figure 1. Methodological model for teaching bioinformatics through digital biological signals and AI technologies

Structure of the Proposed Teaching Methodology

The developed methodology includes four interconnected components: content, technological, activity-based and evaluative components. The content component defines the topics related to biological signals, digital processing, bioinformatics databases and AI algorithms. The technological component includes software environments, open biomedical datasets and visualization tools. The activity-based component is implemented through laboratory work, mini-projects and problem-based tasks. The evaluative component measures students’ knowledge, practical skills, algorithmic thinking and ability to interpret AI-based results.

The main components of the methodology are summarized in Table 1.

Component	Educational function	Expected result
Content	Selection of biosignal, AI and bioinformatics topics	Interdisciplinary knowledge
Technological	Use of datasets, signal processing and AI tools	Digital and analytical skills
Activity-based	Laboratory tasks, projects and case studies	Research and problem-solving competence
Evaluative	Rubrics, tests, portfolios and reflection	Measurable learning outcomes

Table 1. Components of the biosignal- and AI-based teaching methodology

At the first stage, students are introduced to the nature of biological signals and the principles of their digital representation. At the second stage, they learn basic preprocessing operations such as filtering, segmentation and normalization. At the third stage, students extract informative features and apply simple AI models. At the fourth stage, they interpret the obtained results and formulate conclusions. At the final stage, the teacher evaluates both the technical result and the pedagogical quality of students’ reasoning.

This sequence is especially important for doctoral-level pedagogical research because it demonstrates not only the use of technology, but also the methodological transformation of the educational process. The teacher becomes a designer of learning situations, while the student becomes an active participant in data-based research activity.

Pedagogical Effect and Expected Learning Outcomes

The implementation of this methodology is expected to improve several groups of competencies. The first group includes bioinformatics knowledge: understanding of biological signals, biomedical datasets and digital representation of physiological processes. The second group includes algorithmic and analytical skills: preprocessing data, selecting features, building simple models and comparing results. The third group includes research competence: formulating a

problem, working with data, interpreting results and presenting evidence-based conclusions. The fourth group includes reflective competence: evaluating one's own learning strategy and understanding the limitations of AI tools.

From a pedagogical point of view, the effectiveness of the methodology may be assessed through diagnostic tests, laboratory performance, project portfolios, rubrics and reflective questionnaires. The comparison of experimental and control groups can show whether biosignal-based AI tasks contribute to deeper understanding and higher motivation. In this way, the methodology creates a foundation for a full DSc-level experimental study.

Conclusion

Teaching bioinformatics through the digitalization of biological signals and artificial intelligence technologies is a promising methodological direction. It integrates biological knowledge, digital competence, algorithmic thinking and research activity into a single educational process. The proposed methodology helps students understand the real scientific value of bioinformatics and prepares them for solving interdisciplinary biomedical problems.

The concise model presented in this thesis can be used as a basis for developing laboratory assignments, project tasks, diagnostic tools and experimental research procedures. Further work should focus on creating a complete set of teaching materials, validating assessment criteria and testing the methodology in real educational conditions.

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ВОЗМОЖНОСТИ ИСПОЛЬЗОВАНИЯ ОБРАЗОВАТЕЛЬНЫХ ТЕХНОЛОГИЙ НА ОСНОВЕ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА В АКАДЕМИЧЕСКИХ ЛИЦЕЯХ.

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Аннотация. В статье рассматриваются возможности использования образовательных технологий на основе искусственного интеллекта в академических лицеях, их значение в учебном процессе и основные направления практического применения. Инструменты искусственного интеллекта рассматриваются как эффективное средство индивидуализации обучения, подготовки учебных материалов, оценки знаний, создания визуальных материалов и развития навыков самостоятельного обучения учащихся. Особое внимание уделяется вопросам академической честности, проверки достоверности информации, развития критического мышления и обеспечения информационной безопасности.

Ключевые слова. искусственный интеллект, образовательные технологии, академический лицей, цифровое образование, индивидуализация обучения, адаптивные платформы, интерактивное обучение, критическое мышление, академическая честность, информационная безопасность.

В настоящее время эффективное использование цифровых технологий становится одной из важных задач системы образования. Особенно большое значение приобретают технологии искусственного интеллекта, которые создают широкие возможности для

модернизации учебного процесса, повышения учебной активности учащихся и облегчения методической деятельности преподавателя.

Под образовательными технологиями на основе искусственного интеллекта понимаются не только самостоятельные программы искусственного интеллекта, но и цифровые образовательные платформы, обогащённые элементами ИИ. Такие технологии применяются для создания текстов, составления тестов, анализа ответов учащихся, подготовки презентаций, распознавания речи, редактирования текстов и разработки визуальных учебных материалов.

Генеративные инструменты искусственного интеллекта, такие как ChatGPT, Gemini, Microsoft Copilot, Claude и Monica, помогают преподавателям составлять планы уроков, тестовые задания, практические упражнения, тексты презентаций и материалы для самостоятельной работы.

Платформа Perplexity может использоваться для поиска информации на основе источников и формирования у учащихся навыков анализа данных.

В академических лицеях важное значение имеет использование адаптивных образовательных платформ. Такие платформы, как Khan Academy и Duolingo, подбирают учебные материалы с учётом уровня знаний, ошибок и темпа обучения учащегося. Это позволяет обеспечить индивидуальный подход к каждому обучающемуся.

Технологии автоматической оценки способствуют быстрой и эффективной организации учебного процесса. С помощью платформ Wayground, Kahoot и Baamboozle можно проводить тесты, викторины и интерактивные занятия. Эти платформы автоматически анализируют результаты и позволяют определить, по каким темам учащиеся испытывают затруднения.

Особенно эффективно применение искусственного интеллекта в рамках отдельных учебных предметов. Например, при изучении темы «Треугольник и его виды» по математике можно использовать ChatGPT для подготовки теоретического объяснения, тестов и практических примеров. С помощью Gemini можно анализировать геометрические фигуры визуально, а с помощью Canva AI или Gamma — создавать инфографику и презентации. Платформы Kahoot или Baamboozle можно применять для закрепления знаний в игровой и интерактивной форме.

Одним из главных преимуществ искусственного интеллекта является индивидуализация учебного процесса. ИИ помогает подбирать учебный материал в соответствии с уровнем знаний и потребностями каждого учащегося. Кроме того, он способствует экономии времени преподавателя, организации интерактивных уроков, развитию самостоятельной работы учащихся и повышению их цифровой грамотности. Вместе с тем использование искусственного интеллекта сопровождается рядом проблем. Прежде всего, преподаватели должны обладать практическими навыками эффективного применения таких технологий. В связи с этим в академических лицеях целесообразно организовывать практические семинары, краткосрочные тренинги и занятия по обмену опытом.

Ещё одной важной проблемой является чрезмерная зависимость учащихся от готовых ответов, предоставляемых искусственным интеллектом. Это может привести к снижению самостоятельного мышления, аналитических способностей и творческого подхода. Поэтому необходимо формировать у учащихся культуру не простого копирования готовых ответов, а их проверки, анализа, сравнения и дополнения собственными мыслями.

Кроме того, инструменты искусственного интеллекта не всегда предоставляют точную и достоверную информацию. Иногда ответы могут быть неполными, ошибочными или не соответствовать теме. Поэтому материалы, полученные с помощью ИИ, должны проверяться преподавателем и сопоставляться с учебниками, научными источниками и надёжными электронными ресурсами.

Важное значение имеет и информационная безопасность. Учащиеся и преподаватели не должны вводить в открытые платформы искусственного интеллекта личные данные,

оценки, номера телефонов, документы и другую конфиденциальную информацию. В образовательном учреждении целесообразно разработать простые и понятные внутренние правила использования искусственного интеллекта.

Таким образом, образовательные технологии на основе искусственного интеллекта являются эффективным средством повышения качества образования в академических лицах. Они способствуют росту интереса учащихся к учебным предметам, развитию навыков самостоятельного обучения и облегчению методической деятельности преподавателя. Однако искусственный интеллект не должен рассматриваться как замена преподавателя. Он должен использоваться как вспомогательная технология, поддерживающая учебный процесс. Целенаправленное и осознанное применение ИИ способствует формированию цифровых компетенций учащихся и подготовке их к требованиям современного общества.

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SUN’IY INTELEKTNING TA’LIM JARAYONIDAGI INNOVATSION YECHIMLARI

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“Kompyuter tizimlarining dasturiy va texnik ta’minoti” kafedrasida katta o’qituvchisi

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Annatsiya: Ushbu maqolada ta’lim tizimida sun’iy intellektning roli keng qamrovli tahlil qilinadi. Unda sun’iy intellekt texnologiyalarining ta’lim jarayonlariga tatbiqi, o’qitish metodikalaridagi innovatsion o’zgarishlar, shaxsiylashtirilgan ta’lim imkoniyatlari hamda zamonaviy axborot-kommunikatsiya texnologiyalari bilan uyg’unlashuvi masalalari yoritiladi. Shuningdek, maqolada sun’iy intellektning amaliy qo’llanilishidagi afzalliklar, yuzaga kelishi mumkin bo’lgan xavf-xatarlar va ularni bartaraf etish yo’llari ko’rib chiqiladi. Kelajakda bu texnologiyaning ta’lim tizimini qanday o’zgartirishi mumkinligi haqida ham fikr yuritilib, ta’lim jarayonida samaradorlikni oshirishga xizmat qiluvchi innovatsion yechimlar taqdim etiladi.

Kalit so’zlar: sun’iy intellekt, ta’lim, innovatsiya, texnologiya, o’qitish, shaxsiylashtirish, axborot-kommunikatsiya, raqamli ta’lim.

Ta’lim – inson jamiyatining asosi bo’lib, uning sifatini oshirish, yangi avlodni tarbiyalash va kelajak uchun poydevor yaratishda muhim rol o’ynaydi. So’nggi yillarda axborot-kommunikatsiya texnologiyalarining tez sur’atlar bilan rivojlanishi natijasida, sun’iy intellekt konseptsiya va usullarining ta’lim sohasiga tatbiqi ham o’zining yangi bosqichiga kirganini ko’rib turibmiz. Bir paytlarda o’quv jarayonlari an’anaviy usullarga tayanib, darsliklar, ta’lim muassasalari va an’anaviy metodikalar orqali olib borilardi; ammo bugungi kunda innovatsion texnologiyalar va raqamli yechimlar o’quv jarayonlarini yanada samaraliroq, shaxsiylashtirilgan va interaktiv holga keltirish imkonini bermoqda. Sun’iy intellektning ta’limga tatbiqi faqatgina zamonaviy texnologik yutuqlarni namoyish etish emas, balki o’qituvchilar va o’quvchilar o’rtasidagi aloqani yangi darajaga olib chiqish, darslarni interaktiv va individual yondashuv asosida tashkil etish, shuningdek, o’quv jarayonida tezkor va aniqlik bilan tahlil qilish imkoniyatlarini yaratish bilan bevosita bog’liq.

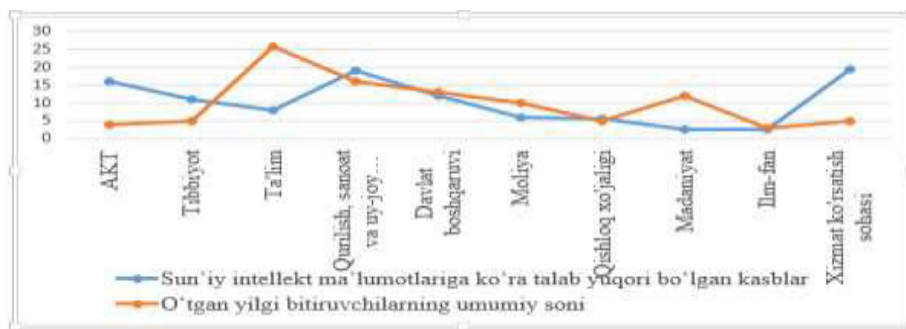
Shu bilan birga, bu texnologiyalar nafaqat o'quv jarayonining sifatini oshiradi, balki o'qituvchilarga o'z ishini samaraliroq rejalashtirish, dars jarayonini kuzatish va baholashda yordam beradi [1]. Bundan tashqari talabalarga kognitiv va psixologik omillar bo'yicha olib borilgan tadqiqotlar sun'iy intellektning ta'lim jarayoniga ko'p qirrali ta'sir ko'rsatishini tasdiqlaydi. Xususan, u o'quvchilarning diqqat, xotira va motivatsiya kabi kognitiv hamda psixologik ko'rsatkichlarini sezilarli darajada yaxshilashga xizmat qilsa-da, meta-kognitiv va ijtimoiy-emotsional kompetensiyalarni rivojlantirish yo'nalishida hali yetarli darajada samaradorlikka erishilmagan. Shu bilan birga, sun'iy intellektni ta'limga integratsiya qilish inson omili, etik me'yorlar va psixologik muvozanatni hisobga olishni talab etadi. Natijada, mazkur texnologiyalarni qo'llashda inson markazidagi yondashuv, pedagogik tayyorgarlik va ijtimoiy moslashuv omillarini uyg'unlashtirish ta'lim samaradorligini oshirish sifatida namoyon bo'ladi. Talabalarga sun'iy intellekt va ma'lumotlarni qayta ishlashni o'qitishda o'quv jarayoni ishtirokchilarining o'zaro muloqot modeli asosida quyidagi kompetentliklarning shakllanishi aniqlandi (1-rasmga).



1-rasm. Talabalarga sun'iy intellekt va ma'lumotlarni qayta ishlashni o'qitishda rivojlanadigan kompetentliklar

O'zbekiston va boshqa davlatlarda ta'lim sohasida sun'iy intellektni tatbiq etish borasida olib borilayotgan tajribalar, innovatsion loyihalar va grantlar orqali o'quv jarayonlarini modernizatsiya qilish bo'yicha ko'plab muvaffaqiyatli misollar mavjud. Masalan, onlayn ta'lim platformalari, adaptiv o'quv tizimlari va intellektual tahlil vositalari yordamida o'quvchilarning bilim darajasi, qiziqishlari va o'rganish uslublari inobatga olinib, individual dars rejalarini shakllantirish imkoniyati yuzaga kelmoqda [2].

Bunday tizimlar o'quvchilarga o'z potensialini maksimal darajada rivojlantirish imkonini berib, ularga nafaqat nazariy bilimlarni, balki amaliy ko'nikmalarni ham egallashda yordam beradi. Shu bilan birga, o'qituvchilar uchun bu texnologiyalar dars mazmunini interaktiv shaklda yetkazib berish, o'quvchilarning fikrlarini tahlil qilish va dars jarayonini real vaqt rejimida monitoring qilish kabi qulayliklarni taqdim etadi [3]. Sun'iy intellektni ta'limda tatbiq etish jarayonida ba'zi muammolar va xavf-xatarlar ham mavjud. Birinchi navbatda, texnologik infratuzilmaning yetarli darajada rivojlanmagan hududlarda bunday yechimlarni joriy etish qiyinchilik tug'dirishi mumkin. Bundan kelib chiqib yurtimizda aniqlangan muammolarni hal etish hamda O'zbekiston – 2030 strategiyasi doirasidagi ustuvor vazifalarni amalga oshirish maqsadida ta'lim tizimini modernizatsiya qilish bo'yicha "Taraqqiyot strategiyasi" markazi mutaxassislari tomonidan sun'iy intellektning tahliliy va prognozlash imkoniyatlaridan foydalanishga qaratilgan bir qator takliflar ishlab chiqildi (2-rasm). Sun'iy intellekt asosida olib borilgan tahliliy tadqiqotlar O'zbekiston mehnat bozorida kadrlar tayyorlash va ularga bo'lgan talab o'rtasida nomutanosiblik mavjudligini ko'rsatdi. Xususan, axborot texnologiyalari sohasida malakali mutaxassislar yetishmovchiligi kuzatilsa, ta'lim yo'nalishlarida bitiruvchilar sonining ortiqchiligi qayd etildi. Shuningdek, sun'iy intellektning to'g'ri va samarali ishlashi uchun katta hajmdagi ma'lumotlarga, zamonaviy algoritmlarga va yetarlicha tajriba asosiga ega bo'lish talab etiladi [4].



2-rasm. Sun'iy intellekt tomonidan aniqlangan talab yuqori kasblar bilan OTMlari bitiruvchilari sonining taqqoslanishi.

Shu sababli, o'qituvchilar, ta'lim muassasalari va davlat idoralari o'rtasida hamkorlik va o'zaro tajriba almashish zarurati ortib bormoqda. Yana bir dolzarb masala – axloqiy va huquqiy cheklolar. Sun'iy intellekt algoritmlarining insoniy xatti-harakatlarga ta'siri, shaxsiy ma'lumotlarni himoya qilish, va ta'lim jarayonida yuzaga kelishi mumkin bo'lgan diskriminatsiya masalalari dolzarb savolga aylangan. Shu bois, texnologiyaning tatbiqi jarayonida maxfiylik va axloqiy me'yorlarga qat'iy rioya qilinishi va tizimlarning shaffofligi hamda nazorat ostida bo'lishi muhim ahamiyatga ega [5].

Sun'iy intellekt yordamida ta'lim jarayonining shaxsiylashtirilishi – bu zamonaviy ta'limning eng yorqin istiqbollardan biridir. Har bir o'quvchi o'ziga xos o'rganish uslubiga ega bo'lib, individual imkoniyatlari va qobiliyatlarini hisobga olgan holda dars jarayonini boshqarish talab etiladi. Adaptiv tizimlar, masalan, o'quvchining oldingi bilim darajasi, o'rganish tezligi va individual qiziqishlari asosida dars materiallarini moslashtirib taqdim etadi, bu esa ularning bilimni mustahkamlash va yanada chuqurroq o'zlashtirish imkonini beradi. Shu bilan birga, bunday tizimlar o'qituvchilarga ham o'z dars jarayonini optimallashtirish, o'quvchilarning kamchiliklarini aniqlash va ularni bartaraf etish bo'yicha tezkor choralar ko'rish imkonini beradi. Shu munosabat bilan, sun'iy intellekt yordamida yaratilayotgan o'quv platformalari va interaktiv darsliklar kelajakda ta'lim tizimini tubdan o'zgartirish, o'quvchilarni raqamli davrga tayyorlashda hal qiluvchi rol o'ynashi kutilmoqda. Texnologik yutuqlar va sun'iy intellektning keng qo'llanilishi bilan birga, o'qituvchilar va ta'lim muassasalari ham yangi rollarga va mas'uliyatlarga duch kelmoqda. An'anaviy dars metodikasi o'rniga, innovatsion texnologiyalarni tatbiq etishda o'qituvchining roli faqatgina bilim beruvchi emas, balki yo'l-yo'riq ko'rsatuvchi, maslahatchi va o'quv jarayonini kuzatib boruvchi sifatida qayta talqin qilinmoqda. Shuningdek, o'qituvchilarning zamonaviy texnologiyalarni o'zlashtirish, ularni samarali qo'llash va o'quvchilarga moslashtirilgan dars rejalarini shakllantirish borasida doimiy malaka oshirish kurslari, seminarlar va treninglardan o'tishi talab etiladi. Bu jarayonda davlat va nodavlat tashkilotlari ham innovatsion ta'lim loyihalarini qo'llab-quvvatlash, moliyaviy va texnik yordam ko'rsatish orqali muhim rol o'ynaydi [6]. Bundan tashqari, sun'iy intellektni tatbiq etishda yuzaga keladigan boshqa dolzarb savol – bu texnologiyaning insoniyat va ta'lim sohasidagi ijtimoiy ta'siri. Texnologik inqilob sharoitida ayrim mutaxassislar sun'iy intellektning o'qituvchilar o'rnini egallashi, insoniy tajriba va didaktik yondashuvning kamayishi kabi xavotirlarni bildiradilar. Ammo, bu jarayonni faqat texnologiyaning rivojlanishi sifatida emas, balki insoniy salohiyat va ijodkorlikni yangi darajaga olib chiqish, o'qituvchilarning innovatsion g'oyalarini qo'llab quvvatlash va ularning faoliyatini yanada samarali tashkil etish imkoniyati sifatida ham ko'rish mumkin. Shu bois, sun'iy intellektning afzalliklarini to'liq hayotga tatbiq etish uchun, uning ijtimoiy, axloqiy va madaniy tomonlarini ham chuqur o'rganish, shu jumladan o'qituvchilar, ota-onalar va ijtimoiy tashkilotlar o'rtasida muloqot va hamkorlikni kuchaytirish zarurati mavjud.

Sun'iy intellekt yordamida shaxsiylashtirilgan ta'lim, adaptiv o'qitish tizimlari, virtual amaliyotlar, real vaqtli monitoring, tahliliy tavsiyalar orqali o'quv sifati oshadi. Shuningdek, imkoniyati cheklangan talabalar uchun moslashtirilgan vositalar ham yaratiladi. O'qituvchi esa boshqaruvchi, yo'naltiruvchi, tahlil qiluvchi rolda namoyon bo'ladi. O'quv jarayoni

shaxsiylashtirilib, sun'iy intellekt yordamida har bir talabaning bilim darajasi, o'zlashtirish tezligi va qiziqishlariga moslashtirilgan o'quv materiallari taqdim etilishi mumkin. Masalan, sun'iy intellekt va adaptiv o'quv platformalari orqali talabalar individual o'quv yo'nalishlari bo'yicha mustaqil ishlash imkoniyatiga ega bo'ladilar.

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MUSTAQIL TA'LIM NATIJALARINI SUN'IY INTELEKT ASOSIDA BAHOLASH METODIKASINI TAKOMILLASHTIRISH

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Annotatsiya. Mazkur tadqiqot ishida oliy ta'lim muassasalarida talabalarining mustaqil ta'lim natijalarini sun'iy intellekt texnologiyalari asosida baholash metodikasini takomillashtirish masalalari yoritilgan. Tadqiqotda kredit-modul tizimi sharoitida mustaqil ta'limni samarali tashkil etish, monitoring qilish va baholash jarayonida zamonaviy sun'iy intellekt texnologiyalaridan foydalanish imkoniyatlari tahlil qilingan. Tadqiqot doirasida ishlab chiqilgan AILearnCheck.uz platformasining funksional imkoniyatlari ham yoritilgan bo'lib, ushbu platforma orqali talabalarining mustaqil ta'lim topshiriqlarini sun'iy intellekt yordamida tekshirish, baholash, monitoring qilish va natijalarni tahlil etish imkoniyatlari ko'rsatib berilgan.

Kalit so'zlar: sun'iy intellekt, mustaqil ta'lim, baholash metodikasi, AILearnCheck.uz, kredit-modul tizimi, pedagogik diagnostika, learning analytics, adaptiv baholash.

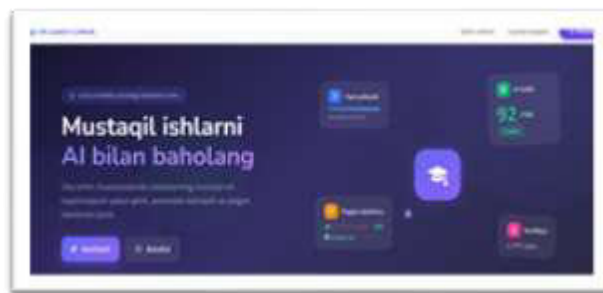
Kirish. Bugungi kunda oliy ta'lim tizimida talabalarining mustaqil ta'lim faoliyatini samarali tashkil etish va obyektiv baholash dolzarb masalalardan biri hisoblanadi. O'zbekiston Respublikasi Prezidentining 2022-yil 28-yanvardagi PF-60-son Farmonida “ta'lim sifatini oshirish, zamonaviy raqamli texnologiyalarni ta'lim jarayoniga keng joriy etish” ustuvor vazifalardan biri sifatida belgilangan [1]. Shu bois, mustaqil ta'lim natijalarini sun'iy intellekt texnologiyalari asosida baholash metodikasini takomillashtirish ta'lim samaradorligini oshirishga xizmat qiladi. Tadqiqotda AI texnologiyalari yordamida avtomatik baholash, pedagogik diagnostika, monitoring va tezkor feedback mexanizmlarini qo'llash imkoniyatlari yoritiladi. Shuningdek, AILearnCheck.uz platformasi misolida mustaqil ta'lim natijalarini obyektiv va shaffof baholashning amaliy mexanizmlari ishlab chiqiladi.

So'nggi yillarda sun'iy intellekt texnologiyalarining ta'lim jarayoniga integratsiyasi mustaqil ta'limni tashkil etish va baholashning yangi imkoniyatlarini yuzaga keltirmoqda. Murodova M.M. sun'iy intellekt vositalari ta'lim jarayonini individuallashtirish, tezkor feedback taqdim etish hamda talabalarining mustaqil ishlash ko'nikmalarini rivojlantirishga xizmat qilishini

ta'kidlaydi [2]. Yo'ldashev Axrorjon va Muxtorov Alijon tadqiqotlarida esa sun'iy intellekt texnologiyalari o'quvchilarning mustaqil o'qish va tahliliy fikrlash kompetensiyalarini shakllantirishda samarali vosita ekanligi asoslab berilgan [3]. Xia Q. tomonidan olib borilgan ilmiy tadqiqotda generativ sun'iy intellekt oliy ta'limdagi baholash tizimlarini transformatsiya qilayotgani, ayniqsa avtomatlashtirilgan baholash va adaptiv diagnostika mexanizmlarini rivojlantirayotgani qayd etilgan [4]. Mazkur ilmiy qarashlar mustaqil ta'lim natijalarini sun'iy intellekt asosida baholash metodikasini takomillashtirish zaruratini ko'rsatadi.

Zamonaviy ta'lim tizimida sun'iy intellekt texnologiyalaridan foydalanish talabalarning mustaqil ta'lim faoliyatini samarali tashkil etish va baholashning muhim vositalaridan biri hisoblanadi. Shu maqsadda ishlab chiqilgan AILearnCheck.uz platformasi talabalarning mustaqil topshiriqlarini avtomatik tekshirish, tahlil qilish va baholash imkoniyatlarini taqdim etuvchi innovatsion raqamli tizim sifatida taklif etiladi. Platforma kredit-modul tizimi talablariga mos ravishda ishlab chiqilgan bo'lib, mustaqil ta'lim jarayonining monitoringini yuritish, topshiriqlarni qabul qilish hamda natijalarni tizimli ravishda saqlash imkonini beradi.

AILearnCheck.uz platformasida sun'iy intellekt algoritmlari yordamida talabalar tomonidan yuklangan matnli topshiriqlar grammatik, mantiqiy va mazmuniy jihatdan tahlil qilinadi. Bundan tashqari, platforma topshiriqlardagi o'xshashlik va nusxalash holatlarini aniqlash orqali baholashning obyektivligini ta'minlaydi. AI texnologiyalari asosida shakllangan baholash mezonlari talabaning mavzuni o'zlashtirish darajasi, mustaqil fikrlashi hamda topshiriqni bajarish sifati haqida aniq diagnostik ma'lumotlarni taqdim etadi. Bu esa o'qituvchiga talabalar faoliyatini tezkor monitoring qilish imkonini beradi.



1-rasm. AILearnCheck.uz platformasining kirish qismi.

Platformaning yana bir muhim jihati — feedback tizimining mavjudligidir. Baholash yakunida talaba o'z ishiga oid tavsiyalar, aniqlangan xatolar va ularni bartaraf etish bo'yicha ko'rsatmalarni oladi. Mazkur yondashuv talabaning o'z ustida ishlashiga, bilim va ko'nikmalarini mustaqil ravishda rivojlantirishiga xizmat qiladi. Shuningdek, platformada learning analytics texnologiyalari qo'llanilib, talabalarning o'quv faolligi, topshiriq bajarish dinamikasi va natijalari bo'yicha statistik tahlillar shakllantiriladi.

AILearnCheck.uz platformasi o'qituvchilar uchun ham qulay boshqaruv vositalarini taqdim etadi. Jumladan, topshiriqlarni yaratish, baholash mezonlarini belgilash, natijalarni eksport qilish va umumiy monitoringni amalga oshirish imkoniyatlari mavjud. Natijada baholash jarayonining tezkorligi, shaffofligi va aniqligi oshadi hamda o'qituvchining vaqt sarfi sezilarli darajada kamayadi. Shu sababli platforma oliy ta'lim muassasalarida mustaqil ta'limni baholash metodikasini takomillashtirishga xizmat qiluvchi samarali pedagogik vosita sifatida namoyon bo'ladi.



2-rasm. Talaba olgan sertifikat va baholash mezonlari bo'yicha tahlil.

Xulosa qilib aytganda, sun'iy intellekt texnologiyalari asosida mustaqil ta'lim natijalarini baholash talabalarining bilimni obyektiv aniqlash, tezkor feedback taqdim etish va ta'lim samaradorligini oshirishda muhim ahamiyat kasb etadi. AILearnCheck.uz platformasi orqali mustaqil topshiriqlarni avtomatik tekshirish, monitoring qilish va diagnostik tahlil etish imkoniyatlari yaratiladi. Natijada baholash jarayonining shaffofligi ta'minlanib, o'qituvchi yuklamasi kamayadi hamda talabalarining mustaqil ishlash ko'nikmalari rivojlanadi [5-9].

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TA'LIMDA SUN'IY INTELLEKT TEXNOLOGIYALARINING O'RNI VA RIVOJLANISH ISTIQBOLLARI

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Bugungi kunda rivojlangan davlatlarda sun'iy intellekt asosida ishlovchi ta'lim platformalari, virtual yordamchilar va intellektual tahlil tizimlari keng qo'llanilmoqda. Globallashuv va raqamli transformatsiya jarayonlari zamonaviy ta'lim tizimining mazmuni hamda shakliga sezilarli ta'sir ko'rsatmoqda. Ayniqsa, sun'iy intellekt texnologiyalarining jadal rivojlanishi ta'lim sohasida yangi pedagogik yondashuvlarni shakllantirishga xizmat qilmoqda. Bugungi kunda dunyo miqyosida bilimlarni uzatish, o'quv jarayonini boshqarish va ta'lim sifatini

nazorat qilishda intellektual tizimlardan keng foydalanilmoqda. Natijada an'anaviy ta'lim modeli bosqichma-bosqich raqamli va interaktiv ta'lim muhiti bilan almashmoqda.

Sun'iy intellektning ta'limga integratsiyalashuvi nafaqat texnologik yangilanish, balki inson kapitalini rivojlantirishning muhim omillaridan biri sifatida baholanmoqda. Chunki mazkur texnologiya o'quvchilarning individual imkoniyatlarini aniqlash, o'quv materiallarini moslashtirish hamda bilimlarni samarali o'zlashtirish jarayonini optimallashtirish imkonini beradi. Shu sababli rivojlangan davlatlarda sun'iy intellekt asosidagi ta'lim platformalarini yaratish strategik yo'nalishlardan biriga aylangan.

Sun'iy intellekt tushunchasining ilmiy mohiyati haqida so'z borganda, Sun'iy intellekt — bu inson tafakkuriga xos bo'lgan tahliliy, mantiqiy va ijodiy faoliyatni kompyuter tizimlari orqali modellashtirishga qaratilgan texnologiyalar majmuasi hisoblanadi. Mazkur tizimlar ma'lumotlarni qayta ishlash, tajriba asosida o'rganish, xulosa chiqarish va mustaqil qaror qabul qilish imkoniyatiga ega bo'ladi. Sun'iy intellektning asosiy tarkibiy qismlariga mashinali o'qitish, neyron tarmoqlar, tabiiy tilni qayta ishlash va ekspert tizimlari kiradi.

Ilmiy nuqtai nazardan, sun'iy intellekt inson va kompyuter o'rtasidagi intellektual hamkorlikni rivojlantiruvchi innovatsion vosita hisoblanadi. Ayniqsa, katta hajmdagi axborotlarni qisqa muddatda tahlil qilish imkoniyati ushbu texnologiyaning samaradorligini oshirmoqda. Shu jihatdan, ta'lim tizimida sun'iy intellektdan foydalanish pedagogik faoliyatni modernizatsiya qilishning muhim bosqichi sifatida e'tirof etilmoqda.

Ta'lim tizimida sun'iy intellektning qo'llanilish yo'nalishlari

Hozirgi davrda sun'iy intellekt texnologiyalari ta'limning turli bosqichlarida faol qo'llanilmoqda. Jumladan, maktabgacha ta'limdan boshlab oliy ta'lim va malaka oshirish tizimigacha bo'lgan jarayonlarda intellektual platformalar muhim ahamiyat kasb etmoqda.

Individual ta'limni shakllantirish

Sun'iy intellektning eng muhim afzalliklaridan biri — individual ta'lim modelini yaratish imkoniyatidir. An'anaviy ta'limda barcha o'quvchilarga bir xil metodika asosida yondashilsa, intellektual tizimlar har bir o'quvchining bilim darajasi, qiziqishi va o'zlashtirish sur'atiga mos dasturlarni tavsiya etadi. Natijada o'quv jarayonining samaradorligi sezilarli darajada ortadi.

Virtual pedagog va chatbot tizimlari

Sun'iy intellekt asosida yaratilgan virtual assistentlar o'quvchilarga real vaqt rejimida yordam ko'rsatish imkoniga ega. Bunday tizimlar savollarga tezkor javob qaytarish, topshiriqlarni tushuntirish va o'quvchilar faoliyatini monitoring qilish vazifalarini bajaradi. Ayniqsa, masofaviy ta'lim jarayonida virtual pedagoglarning ahamiyati yanada ortmoqda.

Baholash va monitoring jarayonlari

Intellektual dasturlar yordamida test natijalari, yozma ishlar va o'quvchilarning faolligi avtomatik ravishda tahlil qilinadi. Bu esa baholash tizimining aniqligi va shaffofligini ta'minlaydi. Shu bilan birga, o'quvchilarning bilim darajasidagi muammolar erta aniqlanib, ular bilan individual ishlash imkoniyati yaratiladi.

Ta'lim analitikasi va prognozlash

Sun'iy intellekt katta hajmdagi ma'lumotlarni tahlil qilish orqali ta'lim sifati bo'yicha prognozlar ishlab chiqadi. Masalan, ayrim tizimlar o'quvchining kelajakdagi akademik natijalarini oldindan taxmin qilish imkoniyatiga ega. Bu esa pedagoglarga samarali strategiyalar ishlab chiqishda yordam beradi.

Sun'iy intellektning ta'limdagi afzalliklari

Ta'lim tizimida sun'iy intellekt texnologiyalaridan foydalanish bir qator ijobiy natijalarni yuzaga keltirmoqda. Avvalo, ta'lim jarayonining interaktivligi va samaradorligi oshmoqda. O'quvchilar uchun qulay va moslashuvchan muhit yaratilayotgani ularning bilim olishga bo'lgan qiziqishini kuchaytirmoqda.

Shuningdek, sun'iy intellekt:

- vaqt va moddiy resurslarni tejaydi;
- pedagogik yuklamani kamaytiradi;
- ta'lim sifatini monitoring qilishni yengillashtiradi;

- masofaviy ta'lim imkoniyatlarini kengaytiradi;
- mustaqil ta'lim ko'nikmalarini rivojlantiradi.

Eng muhimi, mazkur texnologiyalar yordamida zamonaviy mehnat bozoriga mos raqobatbardosh mutaxassislarni tayyorlash imkoniyati kengaymoqda.

Sun'iy intellektdan foydalanishdagi muammolar

Shu bilan birga, sun'iy intellektning ta'limga keng joriy etilishi ayrim murakkab masalalarni ham yuzaga chiqarmoqda. Xususan, texnologiyalarga haddan tashqari bog'liqlik o'quvchilarning mustaqil fikrlash qobiliyatiga salbiy ta'sir ko'rsatishi mumkin. Ayrim hollarda tayyor algoritmlarga tayanish ijodiy tafakkurning sustlashishiga olib keladi.

Bundan tashqari, axborot xavfsizligi va akademik halollik masalalari ham dolzarb hisoblanadi. Sun'iy intellekt yordamida tayyorlangan matnlar va topshiriqlarning nazoratsiz qo'llanilishi plagiat holatlarining ko'payishiga sabab bo'lishi mumkin. Shu bois, ushbu texnologiyalardan foydalanishda pedagogik nazorat va axloqiy me'yorlarga rioya qilish muhim sanaladi.

O'zbekistonda sun'iy intellekt va ta'lim integratsiyasi

O'zbekistonda ham raqamli iqtisodiyot va innovatsion texnologiyalarni rivojlantirish davlat siyosatining ustuvor yo'nalishlaridan biri hisoblanadi. So'nggi yillarda ta'lim tizimiga elektron platformalar, masofaviy o'qitish tizimlari va raqamli resurslarning joriy qilinishi bu sohadagi islohotlarning muhim natijasidir.

Kelajakda sun'iy intellekt texnologiyalarini ta'lim tizimiga keng integratsiya qilish orqali:

- zamonaviy bilim va ko'nikmalarga ega mutaxassislar tayyorlanadi;
- ta'lim sifatining xalqaro standartlarga mosligi ta'minlanadi;
- innovatsion pedagogik metodlar rivojlantiriladi;
- ilmiy tadqiqotlar samaradorligi oshiriladi.

Bu esa mamlakatning intellektual salohiyatini yuksaltirish va global raqobatbardoshlikni ta'minlashda muhim omil bo'lib xizmat qiladi.

Xulosa

Xulosa o'rnida ta'kidlash joizki, sun'iy intellekt texnologiyalari zamonaviy ta'lim tizimining ajralmas qismiga aylanib bormoqda. Mazkur texnologiyalar ta'lim jarayonini takomillashtirish, o'qitish samaradorligini oshirish va individual yondashuvni rivojlantirishda muhim ahamiyat kasb etadi. Shu bilan birga, sun'iy intellektdan oqilona foydalanish, inson omili va pedagogik qadriyatlarni saqlab qolish dolzarb vazifa bo'lib qolmoqda.

Kelgusida sun'iy intellekt asosidagi ta'lim tizimlarining rivojlanishi innovatsion fikrlaydigan, raqobatbardosh va yuqori malakali kadrlarni tayyorlashga xizmat qilishi shubhasiz.

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TALABALARINING FIKRLASHINI RIVOJLANTIRISHDA SUN'IY INTELLEKT TEXNOLOGIYASINING O'RNI

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Annotatsiya. Ushbu ilmiy tezisdagi zamonaviy oliy ta'lim tizimining eng dolzarb vazifalaridan biri - talabalarda kreativ (ijodiy) va tanqidiy fikrlash qobiliyatlarini shakllantirishda sun'iy intellekt (SI) texnologiyalarining o'rni va pedagogik salohiyati atroflicha tadqiq etilgan. Ishda neyrotarmoqlar va intellektual ta'lim tizimlarining dars jarayoniga integratsiyalashuvi, talabalarda axborot xavfsizligi, ma'lumotlarni tahlil qilish, muammolarga nostandart hamda innovatsion yechimlar topish ko'nikmalarini modellashtirish mexanizmlari tahlil qilingan. Shuningdek, SI texnologiyalaridan foydalanishning didaktik afzalliklari bilan bir qatorda, talabalarda yuzaga kelishi mumkin bo'lgan kognitiv passivlik xavflari muhokama etilib, OTMlarda o'quv dasturlarini transformatsiya qilish hamda baholash mezonlarini yangilash bo'yicha ilmiy-amaliy tavsiyalar ilgari surilgan.

Kalit so'zlar: Sun'iy intellekt, generativ neyrotarmoqlar, kreativ fikrlash, tanqidiy fikrlash, oliy ta'lim muassasasi (OTM), didaktik transformatsiya, kognitiv kompetensiya, muammoli ta'lim, raqamli pedagogika.

Kirish

XXI asrning uchinchi o'n yilligiga kelib, global mehnat bozori va sanoat tarmoqlari oliy ma'lumotli mutaxassislariga nisbatan mutlaqo yangi talablarni shakllantirdi. To'rtinchi sanoat inqilobi (Industry 4.0) sharoitida shunchaki fundamental bilimlarga ega bo'lish muvaffaqiyat garovi bo'lolmaydi; zamonaviy kadrlar yuqori darajadagi moslashuvchanlik, kreativlik va chuqur tanqidiy tahlil ko'nikmalariga ega bo'lishi shart. Oliy ta'lim muassasalarining (OTM) an'anaviy o'qitish tizimi ko'p hollarda talabalarga tayyor va qoliplashgan axborotlarni taqdim etishga yo'naltirilgan bo'lib, bu bugungi kun dinamikasiga javob bermay qoldi.

Ushbu sharoitda sun'iy intellekt (SI) texnologiyalari ta'lim tizimiga shunchaki texnik yordamchi vosita emas, balki ta'lim paradigmasini tubdan o'zgartiruvchi transformatsion kuch sifatida kirib keldi. OTM talabalarining intellektual salohiyatini oshirishda SI texnologiyalari o'quv jarayonini individuallashtirish, simulyatsiya muhitlarini yaratish va real vaqt rejimida feedback (teskari aloqa) berish imkoniyatlari bilan ajralib turadi. Kreativlik va tanqidiy fikrlash bir-biri bilan chambarchas bog'liq bo'lib, biri yangi g'oya va yechimlarni loyihalashga mas'ul bo'lsa, ikkinchisi ushbu g'oyalarning mantiqiy asoslarini, to'g'riligini va hayotiy samaradorligini tekshirishni ta'minlaydi. Tezisning maqsadi - OTM talabalarida ushbu ikki muhim kognitiv ko'nikmani shakllantirishda SI vositalarining pedagogik-didaktik salohiyatini aniqlash va tahlil qilishdan iboratdir.

Mavzu bo'yicha tahliliy qism (Literature Review)

Oliy ta'lim tizimida raqamli transformatsiya jarayonlarining jadallashuvi sun'iy intellekt (SI) texnologiyalarini ta'lim jarayoniga keng joriy etishni dolzarb pedagogik va metodologik masalaga aylantirmoqda. Zamonaviy globallashtirish sharoitida oliy ta'lim muassasalari oldida nafaqat bilim berish, balki raqobatbardosh, mustaqil fikrlovchi, kreativ va texnologik kompetensiyalarga ega mutaxassislarni tayyorlash vazifasi turibdi. Shu nuqtai nazardan, sun'iy intellekt texnologiyalarini ta'lim jarayoniga integratsiya qilishning ilmiy-nazariy asoslarini tahlil qilish muhim ahamiyat kasb etadi.

Sun'iy intellekt - bu inson tafakkuriga xos bo'lgan tahlil qilish, o'rganish, mantiqiy xulosa chiqarish, qaror qabul qilish va muammoni hal etish kabi funksiyalarni bajarishga qodir bo'lgan dasturiy va texnologik tizimlar majmuasidir. Oliy ta'limda SI texnologiyalaridan foydalanish o'quv jarayonini individuallashtirish, ta'lim sifatini oshirish, talabalar faoliyatini monitoring qilish, adaptiv o'qitish muhitini yaratish hamda pedagogik boshqaruvni optimallashtirish imkonini beradi.

Sun'iy intellektning ta'lim sohasidagi roli so'nggi yillarda xalqaro miqyosda eng ko'p o'rganilayotgan ilmiy muammolardan biridir. YUNESKO tomonidan qabul qilingan strategik hujjatlar va yo'riqnomalarda ta'kidlanishicha, generativ SI tizimlari (masalan, ChatGPT, Gemini, Claude, shuningdek vizual platformalar Midjourney, DALL-E) ta'limda inklyuzivlikni ta'minlash bilan birga, talabalarni loyihaviy va muammoli fikrlashga undaydi. Biroq, xalqaro ekspertlar (masalan, Anderson, 2023; Selwyn, 2024) neyrotarmoqlarning ta'limdagi o'rni bir tomonlama emasligini, ular talabaning mustaqil tadqiqotchilik faoliyatini ham bo'g'ishi, ham rag'batlantirishi mumkinligini qayd etishadi.

Tanqidiy fikrlash nazariyasiga ko'ra, inson ma'lumotni qabul qilar ekan, undagi mantiqiy xatoliklarni, stereotiplarni va manipulyatsiyalarni ajrata olishi kerak. SI modellarining katta hajmdagi ma'lumotlar ("Big Data") asosida ishlashi uning ba'zan noto'g'ri, eskirgan yoki "Gallyusinativ" (to'qib chiqarilgan) faktlarni haqiqat sifatida taqdim etishiga sabab bo'ladi. Bu holat pedagogik nuqtai nazardan o'ziga xos didaktik trigger vazifasini o'taydi: talaba SI dan olgan javobini ko'r-ko'rona qabul qilolmaydi, uni an'anaviy akademik manbalar, ilmiy adabiyotlar va statistik bazalar bilan solishtirishga majbur bo'ladi. SIning kamchiliklari bilvosita talabalarda "Fact-Checking" (faktlarni tekshirish) madaniyatini va tanqidiy filtni shakllantiradi.

Kreativlik masalasiga kelsak, ko'plab zamonaviy tadqiqotlar shuni ko'rsatadiki, SI inson tasavvur doirasini kengaytirishga xizmat qiladi. Ilgari talaba bitta kreativ g'oyani vizuallashtirish yoki algoritmik modelini yaratish uchun haftalab vaqt sarflagan bo'lsa, bugungi kunda neyrotarmoqlar bir necha soniya ichida o'nlab konseptual variantlarni taklif eta oladi. Bu esa talabaga past darajali texnik ishlardan qutulib, yuqori darajali konseptual tahlil va ijodiy sintez bilan shug'ullanish imkonini beradi.

Asosiy qism.

Tanqidiy fikrlashni rivojlantirishda Sun'iy intellekt modellarining didaktik imkoniyatlari.

OTM talabalarida tanqidiy fikrlashni shakllantirish shunchaki nazariy qoidalarni yodlatish bilan amalga oshmaydi. Bu jarayon interaktiv va evristik muhitni talab qiladi. Sun'iy intellekt platformalari quyidagi pedagogik metodlar orqali talabani tahliliy apparatini o'stiradi:

1.Sokratik muloqot va Argumentatsiya treningi. Talaba SI modeli bilan ma'lum bir mavzu yuzasidan intellektual debatlar olib borishi mumkin. Bunda talaba o'zining tezisini ilgari suradi, SI esa unga qarshi argumentlar (counterarguments) va mantiqiy savollar beradi. Masalan, iqtisodiyot yo'nalishi talabasi SIga "Inflyatsiyani jilovlashda soliq stavkalarini oshirish eng samarali yo'ldir" degan tezis tashlasa, SI uning zaif tomonlarini ko'rsatib, muammoning muqobil yechimlarini talab qiladi. Bu muloqot talabani o'z fikrini mantiqiy izchillikda qurishga va dalillar keltirishga o'rgatadi.

2.Anomaliyalarni aniqlash (Bug Bounty in Texts). Pedagogik amaliyotda yangi metod — SI tomonidan ataylab xatoliklar bilan yozilgan matnlar yoki dasturlash kodlarini talabalarga tarqatish va ulardan mantiqiy hamda faktologik xatolarni topishni talab qilishdir. Bu metod talabani diqqat-e'tiborini, detallarga bo'lgan sezgirlikni va tahlil chuqurligini bir necha barobar oshiradi.

3.Ko'p mezonli qarorlar qabul qilish simulyatsiyasi. Tibbiyot, huquqshunoslik yoki menejment yo'nalishi talabalari uchun SI yordamida murakkab Keys-stadi (Case study) vaziyatlari yaratiladi. SI real vaqtda vaziyatni o'zgartirib boradi (masalan, bemorning ahvoli yomonlashishi yoki bozordagi kutilmagan inqiroz) va talaba har bir qadamini tanqidiy tahlil qilib, qaror qabul qilishi lozim bo'ladi.

Kreativlikni rag'batlantirish va "Konseptual kombinatorika". Kreativlik ko'pincha kutilmagan assotsiatsiyalar va turli sohalar chorrahasida tug'iladi. Sun'iy intellekt talabalar uchun cheksiz g'oyalar asissenti (Co-creativity tool) bo'la oladi:

Evristik "Bainstorming" (Aqliy hujum). Yangi innovatsion loyiha yoki startap yaratish bosqichida talabalar ko'pincha "ijodiy turg'unlik" (creative block) holatiga tushib qolishadi. SI an'anaviy fikrlash doirasidan tashqarida bo'lgan, kutilmagan konseptual birikmalarni taqdim etishi mumkin. Masalan, ekologiya va IT sohasini birlashtirgan holda "aqli chiqindi qutilari uchun o'yinlashtirilgan (gamified) mobil ilova" g'oyasini rivojlantirish bo'yicha SI 20 dan ortiq ssenariyni taklif qila oladi.

Tezkor prototiplash va vizuallashtirish. Mashinasozlik, me'morchilik va san'at yo'nalishlarida talaba o'z miyasidagi g'oyani qog'ozga ko'chirish uchun uzoq vaqt sarflaydi. Midjourney, Stable Diffusion kabi grafik neyrotarmoqlar yordamida yuzlab dizayn-konseptlarni soniyalarda yaratish va ularni kombinatsiya qilish orqali butunlay yangi uslubdagi arxitektura yoki muhandislik elementlarini kashf etish mumkin.

Matnlarni stilistik transformatsiya qilish. Filologiya va jurnalistika talabalari SI yordamida bitta ilmiy matnni badiiy, publitsistik yoki biznes uslubiga o'tkazish orqali tilning kreativ imkoniyatlarini va so'z o'yinlarini chuqur o'rganadilar.

Oliy ta'limda akademik yuklamaning ortishi o'qituvchilardan katta vaqt va resurs talab qiladi. Sun'iy intellekt texnologiyalari testlarni avtomatik tekshirish, talabalarning o'zlashtirish darajasini monitoring qilish, elektron resurslarni tavsiya etish kabi vazifalarni bajarish orqali pedagog faoliyatini yengillashtiradi. Natijada o'qituvchi ko'proq ilmiy-tadqiqot va ijodiy pedagogik faoliyat bilan shug'ullanish imkoniyatiga ega bo'ladi. Sun'iy intellekt asosidagi ta'lim tizimlari - bu mashinaviy o'rganish, adaptiv algoritmlar, ma'lumotlarni tahlil qilish va avtomatlashtirilgan boshqaruv asosida ishlovchi raqamli ta'lim platformalaridir.

Muhokama va tahliliy muammolar.

SI texnologiyalarini OTMlarga joriy etish faqat ijobiy natijalardan iborat emas. Bu jarayonda jiddiy psixologik, pedagogik va etik muammolar yuzaga kelmoqda. Eng birinchi va xavfli tendensiya - bu kognitiv plagiat va intellektual passivlikdir. Agar talaba berilgan har qanday mustaqil ish, insho yoki loyihani hech qanday tahlilsiz SIga yozdirib olsa va uni shunchaki o'qituvchiga topshirsa, bu jarayon talabaning fikrlash qobiliyatini rivojlantirish o'rniga, uning butunlay atrofiyaga uchrashiga (kognitiv qaramlikka) olib keladi.

Ikkinchi muammo – “Algorithmic bias” (Algoritmik tarafdashlik). SI modellari internetdagi mavjud ma'lumotlar asosida o'qitilgani sababli, ular ma'lum bir madaniy, ijtimoiy yoki siyosiy qarashlarga yon bosishi mumkin. Agar talabada tanqidiy fikrlash yetarli bo'lmasa, u SIning biryoqlama qarashlarini mutloq haqiqat deb qabul qiladi.

Shu sababli, oliy ta'lim dars berish uslubiyoti zudlik bilan o'zgarishi shart. Baholash tizimi talabaning “nima bilishini” emas, balki uning “qanday fikrlashini” tekshirishi kerak. Masalan, talaba darsga tayyor insho olib kelishi talab qilinmaydi, aksincha, u auditoriyada SI yordamida insho loyihasini yaratadi va o'qituvchi oldida SIning argumentlariga qarshi o'zining mustaqil tanqidiy fikrlarini og'zaki himoya qiladi.

Xulosa qilib aytganda Sun'iy intellekt texnologiyalari zamonaviy OTM talabalarining kreativ va tanqidiy fikrlashini rivojlantirishda misli ko'rilmagan kuchli didaktik quroldir. U ta'limni bir xillikdan qutqarib, uni dinamik, individual va tadqiqotchilik xarakteriga ega bo'lgan jarayonga aylantiradi. Biroq, SIning muvaffaqiyati uning texnik mukammalligida emas, balki talaba va o'qituvchining undan qay darajada to'g'ri va maqsadli foydalana olishidadir.

Talabalarni SI vositalaridan ko'r-ko'rona nusxa ko'chirish uchun emas, balki o'z intellektini o'stiruvchi hamkor (Co-pilot) sifatida foydalanishga o'rgatish lozim. Kelajakda ta'lim tizimining raqobatbardoshligi professor-o'qituvchilarning SI imkoniyatlarini dars ssenariylariga mantiqiy va kreativ tarzda integratsiya qila olish qobiliyati bilan belgilanadi.

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**ANALYSIS OF THE EFFECTIVENESS OF AN ADAPTIVE TEACHING
METHODOLOGY BASED ON ARTIFICIAL INTELLIGENCE TECHNOLOGIES**
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Abstract: This article analyzes how AI-based adaptive teaching improves educational effectiveness by supporting person-centered learning in digital environments. It explains how adaptive systems adjust content to learners' knowledge, pace, progress and individual needs. The study discusses machine learning, learning analytics, NLP, knowledge graphs, recommendation algorithms and key design stages. Comparative analysis shows that personalized learning paths, timely feedback and automated diagnostics enhance outcomes, engagement, independent learning skills and overall quality, making AI-supported adaptive teaching a promising direction for flexible digital education.

Key words: artificial intelligence; adaptive teaching; adaptive learning; machine learning; learning analytics; digital pedagogy; personalization; learning effectiveness.

Introduction

Modern education is changing rapidly under the influence of global digitalization. Traditional teaching methods often provide the same content, tasks and pace for all learners, although students differ in prior knowledge, cognitive readiness, motivation, learning speed and preferred forms of interaction. As a result, some learners master the material quickly, while others need additional support, repetition and more gradual learning pathways. This mismatch reduces educational effectiveness and makes it difficult for teachers to provide timely individualized support in large groups.

Artificial intelligence technologies create new opportunities for designing smart learning environments that respond to learners' actual progress. An adaptive teaching system can diagnose the student's initial level, analyze mistakes, monitor the dynamics of task completion and automatically select content, exercises or feedback according to the learner's current state. In this sense, AI-based adaptive teaching is not simply the use of digital tools in the classroom; it is a methodological system that integrates diagnostics, content modeling, pedagogical decision-making and continuous feedback [1].

Theoretical Foundations of Adaptive Teaching Systems

The theoretical foundations of adaptive teaching systems are associated with the development of intelligent tutoring systems and computer-supported individualized instruction. Early intelligent tutoring systems demonstrated that a digital environment could represent domain knowledge, model learner performance and provide targeted feedback. In modern adaptive learning, these principles are expanded through data-driven algorithms, learning analytics and AI-based prediction models [2].

A contemporary adaptive teaching system usually includes four interrelated components. The first component is the student model, which stores data about the learner's knowledge level, skills, learning pace, mistakes, motivation and behavioral activity. The second component is the content model, where learning materials are structured according to topics, prerequisites, learning objectives, difficulty and semantic relationships. The third component is the pedagogical module, which decides what content, task or feedback should be offered at a particular moment. The fourth component is the interface module, which provides interaction through text, graphics, audio, video, tests, simulations and communication tools.

Artificial Intelligence Methods and Their Application in Adaptive Learning

AI technologies used in adaptive teaching cover several methodological and technical directions. Machine learning algorithms analyze students' answers, task completion time, number of attempts, error types and behavioral traces in order to predict mastery levels. Decision trees, random forests, gradient boosting and neural networks can be used to classify learners according to risk level, recommend additional exercises or identify topics that require reinforcement [4].

Design Stages of an AI-Based Adaptive Teaching Methodology

The design of an AI-based adaptive teaching methodology should be organized as a step-by-step pedagogical and technological process. The first stage is analysis and requirements formation. At this stage, the target audience, learning objectives, educational standards, initial knowledge level and pedagogical constraints are determined. Without this stage, adaptation may become technically complex but pedagogically weak.

The second stage is the creation of data architecture. A database or learning record store is designed to collect student profiles, assessment results, content metadata and learning activity logs. The third stage is the development of a diagnostic module. Entry tests, formative assessment tasks, computer-adaptive testing and item analysis can be used to determine the learner's initial and current mastery levels.

The fourth stage is the creation of a personalized learning path. Based on the student model and content model, the system selects learning materials and tasks according to the learner's current state and target outcome. Algorithms such as shortest-path search, prerequisite analysis and recommendation models may be applied. The fifth stage is the feedback and motivation system. Immediate, clear and supportive feedback helps learners correct mistakes, while gamification elements, progress indicators and individualized recommendations can increase motivation.



Figure 1. Design Stages of an AI-Based Adaptive Teaching Methodology

Research Methodology

The research methodology is based on comparison, observation, statistical analysis and pedagogical experiment. Two groups of students were compared: the first group studied through traditional teaching methods, while the second group studied with the support of an AI-based adaptive learning platform. The criteria for analysis included learning outcomes, independent work ability, speed of completing assignments, consolidation of knowledge and intensity of interaction with the digital platform.

The adaptive platform changed task complexity according to previous results and provided individual recommendations. It also recorded the number of attempts, types of mistakes and the time spent on learning tasks. These data were used to update the learner model and to select reinforcement activities. The comparison of initial and final learning results made it possible to evaluate the effectiveness of the adaptive methodology.

Table 1. Comparative Learning Outcomes in Traditional and AI-Based Adaptive Teaching

Teaching type	Initial result (%)	Final result (%)
Traditional teaching	56	71
AI-based adaptive teaching	58	86

Practical Results and Effectiveness Analysis

The comparative results show that both groups improved their learning outcomes, but the improvement was greater in the group that used AI-based adaptive teaching. In the traditional group, the result increased from 56% to 71%, which means an improvement of 15 percentage points. In the adaptive group, the result increased from 58% to 86%, which means an improvement of 28 percentage points. This indicates that individualized task selection, continuous diagnostics and immediate feedback can significantly strengthen the learning process.

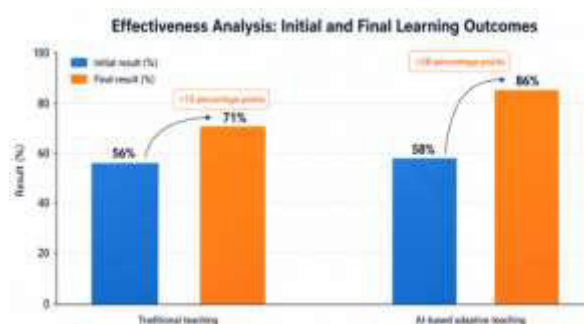


Figure 2. Initial and Final Learning Outcomes by Teaching Type

The reported practical analysis also emphasizes several advantages of adaptive systems. First, the learning pace becomes more flexible because students receive tasks at a level appropriate to their current readiness. Second, learning gaps can be identified earlier, since the system continuously records errors and performance changes. Third, engagement can increase when students see progress, receive timely feedback and work with materials that match their needs. These factors help improve the quality of knowledge consolidation and reduce the risk of passive participation.

At the same time, the implementation of AI-based adaptive teaching faces certain limitations. A sufficient amount of high-quality educational data is required for reliable algorithmic decisions. The development of natural language processing models for the Uzbek language remains a relevant challenge. In addition, teachers need digital and methodological training in order to correctly interpret learning analytics and integrate adaptive recommendations into the educational process.

Discussion

The obtained results are consistent with the general idea that adaptive teaching supports more individualized and effective learning. The main pedagogical value of AI lies in its ability to process a large amount of learning data and convert it into practical recommendations. However, the effectiveness of such systems depends on the quality of pedagogical design. If adaptation is based only on technical indicators and does not take into account learning objectives, cognitive load and the logic of the subject, the system may not produce meaningful educational improvement [7].

For higher education institutions, AI-based adaptive teaching can be especially useful in large groups, blended learning environments and disciplines where students demonstrate very different levels of prior knowledge. It can also help organize independent learning, monitor progress and provide timely intervention. Nevertheless, successful implementation requires institutional readiness, stable technical infrastructure, quality content, data privacy standards and continuous professional development for teachers.

Conclusion

In conclusion, an adaptive teaching methodology based on artificial intelligence technologies is a promising pedagogical approach for improving educational effectiveness. The analysis shows that AI-supported adaptive systems can diagnose students' knowledge level, adjust task complexity, build personalized learning paths and provide timely feedback. These functions help increase learning outcomes, strengthen independent learning skills and improve student engagement.

The comparative data demonstrate that the AI-based adaptive group achieved a higher increase in final results than the traditional group. This confirms the methodological value of individualized learning trajectories and continuous learning analytics. At the same time, the effectiveness of adaptive teaching depends on the quality of educational data, the availability of relevant digital content, teacher readiness and the correct integration of AI recommendations into the pedagogical process.

Future work should focus on developing localized adaptive platforms, improving Uzbek-language NLP tools, expanding digital learning resources and preparing teachers to use learning analytics in practice. In this way, artificial intelligence can become an important component of

modern digital pedagogy and contribute to the development of flexible, learner-centered and high-quality education.

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SUN'IY INTELLEKTGA TAYANGAN INTERAKTIV O'QITISH TIZIMI HAMDA SQL O'QITISH PLATFORMASINI YARATISHNING NAZARIY-USLUBIY ASOSLARI

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Annotatsiya. Ushbu maqolada sun'iy intellekt texnologiyalariga asoslangan interaktiv avtomatlashtirilgan o'qitish tizimi hamda SQL o'qitish platformasini yaratishning nazariy-uslubiy asoslari tadqiq etilgan. Tadqiqotda adaptiv ta'lim, kognitiv yuk nazariyasi va so'rov bajarilish rejasidan foydalanish orqali SQL buyruqlarini samarali o'qitish usullari yoritilgan. Shuningdek, platformada foydalanuvchilarning bilim darajasini aniqlash, xatolarni tahlil qilish va individual tavsiyalar berish imkoniyatlari ko'rib chiqilgan. Taklif etilgan yondashuv o'quv jarayonining interaktivligini oshirish, murakkab SQL so'rovlarini tushunishni yengillashtirish hamda ta'lim samaradorligini kuchaytirishga xizmat qiladi.

Kalit so'zlar. sun'iy intellekt, interaktiv o'qitish tizimi, avtomatlashtirilgan ta'lim, SQL o'qitish platformasi, adaptiv ta'lim, kognitiv yuk nazariyasi, pro-test, post-test, ma'lumotlar bazasi, raqamli ta'lim texnologiyalari, ta'limni avtomatlashtirish.

Sun'iy intellekt texnologiyalarining ta'limga kirib borishi o'quv jarayonini tashkil etishning an'anaviy paradigmalarini sezilarli darajada o'zgartirmoqda. O.Zawacki-Richter va boshqalar oliy ta'limda sun'iy intellekt ilovalarini o'rganishga bag'ishlangan tizimli ko'rib chiqishda sun'iy intellekt yordamida ta'limni shaxsiylashtirish, real vaqtda fikr-mulohaza berish va talabning bilim darajasiga moslashish imkoniyati pedagogika uchun yangi istiqbollar ochishini ta'kidlaydilar. Biroq ushbu imkoniyatlarni, xususan, ma'lumotlar bazasi fanini o'qitish metodikasiga tatbiq etishning pedagogik jihatdan asoslangan nazariy-uslubiy asoslari hali yetarlicha ishlab chiqilmagan. Mazkur paragrafda sun'iy intellektga tayangan interaktiv avtomatlashtirilgan o'qitish tizimi va so'rovni amalga oshirish rejasiga tayangan SQL o'qitish platformasini yaratishning didaktik, metodologik va texno-pedagogik asoslari tizimli ravishda yoritiladi.

Aqlli o'qitish tizimlari sun'iy intellektga asoslangan, talabning bilim darajasini dinamik kuzatib, o'quv mazmuni va yordam darajasini moslashtirishga qodir pedagogik dasturiy tizimlar sifatida tavsiflanadi. Zamonaviy aqlli o'qitish tizimlari, odatda, to'rtta asosiy komponentdan iborat: bilimlar modeli, talaba modeli, pedagogik modul va foydalanuvchi interfeysi. R. Francisco va F. Silva tomonidan o'tkazilgan adabiyotlar ko'rib chiqishida kompyuter fanlari ta'limida qo'llanilgan aqlli o'qitish tizimlarining o'quv natijalariga ijobiy ta'siri qayd etilgan [1].

Ma'lumotlar bazasi va SQL o'qitishga mo'ljallangan maxsus aqlli o'qitish tizimlari nisbatan yangi, ammo tez rivojlanayotgan ilmiy yo'nalishni tashkil etadi. A. Balderas va boshqalar tomonidan ishlab chiqilgan chatbot asosidagi SQL o'qitish platformasi talabaga bosqichli yo'naltiruvchi ishora berish, xatolarni aniqlash va tuzatish bo'yicha tavsiyalar taqdim etish imkoniyatiga ega. Shunga o'xshash, R. Pérez-Mercado va boshqalar tomonidan ishlab chiqilgan ChatbotSQL tizimi munosabatli ma'lumotlar bazasi so'rov tilini o'rganishda suhbatdosh dastur imkoniyatlarining pedagogik samarasini ko'rsatgan.

Generativ sun'iy intellekt, xususan katta til modellarining paydo bo'lishi aqlli o'qitish tizimlarini yangi bosqichga olib chiqdi. P. Bassner, E. Frankford va S. Krusche tomonidan ishlab chiqilgan Iris nomli sun'iy intellektga asoslangan virtual repetitor tizimi talabning javoblarini tahlil

qilish, xatolarni turkumlash va kontekstga mos ishora berish imkoniyatini yaratgan [2]. A.T. Neumann va boshqalar ma'lumotlar bazasi va axborot tizimlari fanida katta til modellariga asoslangan suhbatdosh dasturlardan foydalanish talabalarning tushunish va izohlash ko'nikmalarini kuchaytirishini ko'rsatganlar.

Aqlli o'qitish tizimlarini loyihalashda kognitiv yuk nazariyasi markaziy nazariy asoslardan biri sifatida namoyon bo'ladi. Ushbu nazariyaga ko'ra, talabani ish xotirasi cheklangan bo'lib, o'quv samaradorligi ichki bilish yuki, tashqi bilish yuki va bilimlarni tizimlashtirish yukining o'zaro muvozanatiga bog'liq. T.W. Kim ta'kidlashicha, sun'iy intellekt vositalaridan ta'limda foydalanishda kognitiv yukni boshqarish, tushuntirishning izchilligi va akademik halollikni ta'minlash eng muhim didaktik tamoyillardandir.

Shu asosda "bosqichma-bosqich yo'naltiruvchi ishora" protokoli ishlab chiqiladi. Ushbu protokolda yordam darajalari bosqichma-bosqich oshiriladi: avval mohiyatni ochuvchi ishora, keyin tuzilmaviy ko'rsatma, so'ng operator yoki vositaga ishora, zarur holatda so'rovni amalga oshirish rejasining sharhi va yakunda o'z-o'zini tekshiruv ro'yxati taqdim etiladi. To'liq yechim esa faqat talabani mustaqil ishlash va asoslanishi mavjud bo'lgandagina ochiladi. D. Lyu va boshqalar bosqichli ishora yondashuvining uzoq muddatli o'zlashtirish ko'rsatkichlariga ijobiy ta'sir qilishini qayd etadi [3].

Mazkur protokolning muhim vazifalaridan biri akademik halollikni ta'minlashdir. Sun'iy intellekt vositalarining keng tarqalishi bilan tayyor javobdan noqonuniy foydalanish, plagiarizm va haddan tashqari avtomatlashtirilgan yordamga tayanish muammolari kuchaymoqda. Shu sababli texnik aniqlash vositalaridan tashqari, didaktik protokollar darajasida halollikni kafolatlovchi yondashuvlar zarur.

So'rovni amalga oshirish rejasini tushuntirish va tahlil qilish metodi ma'lumotlar bazasini boshqarish tizimining so'rovni bajarish uchun tanlagan algoritmlarini tahlil qilishga tayangan o'qitish usuli sifatida qaraladi. Ushbu metodning didaktik ahamiyati shundaki, u talabaga "so'rov nima uchun bunday bajarildi?" va "nega unumdorlik past yoki yuqori bo'ldi?" degan savollarga dalilga tayangan javob berish imkonini yaratadi.

K. Prakash va boshqalar ta'kidlashicha, talabani so'rovni amalga oshirish rejasini o'qish, tushuntirish va asoslash ko'nikmasi ma'lumotlar bazasi ta'limining muhim chiqish natijalaridan biridir. Ushbu metodning asosiy funksiyalari: tushuntiruvchi, diagnostik va bashoratlovchi funksiyalardir. Tushuntiruvchi funksiya talabaga tizimning qaror qabul qilish mantig'ini ochib beradi; diagnostik funksiya unumdorlik muammolarining sababini aniqlashga yordam beradi; bashoratlovchi funksiya esa so'rovni qayta yozish yoki indeks yaratish natijasini oldindan baholash imkonini beradi.

Taklif etilgan sqlustoz.uz ta'lim platformasi to'rt asosiy qatlamdan iborat texno-pedagogik arxitektura ega: foydalanuvchi qatlami, amaliy qatlam, sun'iy intellekt xizmati qatlami va ma'lumotlar qatlami. Foydalanuvchi qatlami orqali ma'ruza, laboratoriya, test va loyiha topshiriqlari uzatiladi; amaliy qatlamda brauzerda ishlovchi muhitda turli MBBTlar ishga tushiriladi; sun'iy intellekt xizmati xatolarni tahlil qiladi, ishora beradi va izohlovchi ssenariylar yaratadi; ma'lumotlar qatlamida esa faoliyat yozuvlari, baholash natijalari va individual profillar saqlanadi. Uslubiy qo'llanmada ham topshiriqlarni 3 urinish asosida bajarish, xatolarni avtomatik aniqlash va tezkor tavsiya berish mexanizmi tavsiflangan[5].

Platformaning pedagogik xususiyatlari quyidagilardan iborat: sun'iy intellekt mentor sifatida ishlaydi; baholash tizimi bir nechta mezon asosida quriladi; urinishlar soni cheklanadi; sertifikatlash mexanizmi natijaga bog'lanadi. R.M. Rahman va Y. Watanobe ta'kidlaganidek, sun'iy intellekt ta'limga joriy etishda imkoniyatlar va xavflar o'rtasidagi muvozanatni saqlash strategik vazifa hisoblanadi [2].

Platformaning muhim qo'shimcha qiymati - talaba faoliyati yozuvlari asosidagi tahlil tizimidir. Bu tizim yo'naltiruvchi ishora soni, qayta urinishlar, bajarish vaqti, xato turlari va ko'nikma profili kabi ko'rsatkichlarni avtomatik yig'adi. R. Sajja va boshqalar o'quv jarayonida sun'iy intellekt va learning analytics integratsiyasi o'qituvchiga ma'lumotga asoslangan pedagogik qarorlar qabul qilish imkonini yaratishini ko'rsatganlar. Biroq ushbu manba sizning yakuniy

ro'yxatingizda mavjud emas, shu sababli uni matn ichidagi bibliografik havola sifatida emas, nazariy izoh darajasida qoldirish maqsadga muvofiq. Asosiy tayanch sifatida Zawacki-Richter, Rahman va boshqa bibliografiyada mavjud manbalarga suyanish lozim.

Interaktiv ta'lim platformasi konstruktivizm, faoliyat nazariyasi va yaqin rivojlanish zonasi yondashuvlariga tayangan holda loyihalanadi. Shu sababli platforma tayyor ma'lumotni passiv qabul qilishdan ko'ra, talabani o'zi so'rov yozib, natijani ko'rib, tahlil qilib va qayta yozib o'zlashtirishi uchun faol muhit yaratadi. Faoliyat "faol -> konstruktiv -> o'zaro hamkorlikdagi" bosqichlarda tashkil etiladi. S. Grassini generativ sun'iy intellektni ta'limga joriy etishda aynan shunday bosqichma-bosqich pedagogik qurilmaning muhimligini ta'kidlaydi.

Interaktiv platformaning samaradorligini isbotlashda nazorat va tajriba guruhlarining boshlang'ich ekvivalentligini ta'minlash, pre-test va post-test natijalarini matematik-statistik qayta ishlash, kechiktirilgan tekshiruvlar orqali bilim barqarorligini o'lchash va faoliyat yozuvlari bilan yakuniy natijalar o'rtasidagi bog'lanishni tahlil qilish zarur. I. Kazanidis va N. Pellas generativ sun'iy intellekt asosidagi ta'lim tizimlarida ko'p qatlamli monitoring va natijalarni bashoratlash yondashuvining ilmiy ishonchlilikni oshirishini ko'rsatganlar.

Zamonaviy axborot tizimlari arxitekturasida munosabatli va munosabatli bo'lmagan ma'lumotlar omborlarining uyg'un qo'llanilishi keng tarqalgan [4]. Shu sababli interaktiv ta'lim platformasida hujjatga yo'naltirilgan, kalit-qiyamat va graf omborlari bo'yicha simulyatsiya modullari ham kiritilishi lozim. S. Lee va K.-S. Song sun'iy intellekt tomonidan yaratilgan konseptual tushuntirishlardan foydalanish talabani murakkab tushunchalarni anglash sifatini yaxshilashini ko'rsatadi [3].

NoSQL omborlari bo'yicha o'quv dasturida CAP teoremasi, BASE yondashuvi va ACID tamoyillari qiyosiy tarzda o'rgatilishi kerak. D. Sun va boshqalar ChatGPT yordamida dasturlash ta'limida turli texnologik yondashuvlar o'rtasidagi dizayn tanlovlarini tushuntirish samaradorligini ko'rsatganlar. Bu sqlustoz.uz platformasida NoSQL modullarini sun'iy intellekt bilan uyg'unlashtirish metodik jihatdan asosli ekanini ko'rsatadi.

Amalga oshirilgan tizimli tahlil asosida quyidagi xulosalar chiqarildi. Birinchidan, "Ma'lumotlar bazasi" fani axborot texnologiyalari ta'limida yadro fan sifatida tushunchaviy tafakkur, formal dizayn, transaksion intizom va ishlash samaradorligini bir butun kompetensiyalar majmuasi sifatida shakllantiradi. Ikkinchidan, jahon tajribasi qiyosiy tahlili O'zbekiston oliy ta'lim muassasalarida so'rovni amalga oshirish rejasini tushuntirish va tahlil qilish metodikasi, NoSQL integratsiyasi va faoliyat yozuvlari asosidagi monitoring tizimi yetarli darajada rivojlanmaganini ko'rsatdi. Uchinchidan, sun'iy intellektga tayangan interaktiv avtomatlashtirilgan o'qitish tizimi va so'rovni amalga oshirish rejasiga tayangan SQL o'qitish platformasini yaratishning nazariy-uslubiy asoslari aqlli o'qitish tizimlari nazariyasi, kognitiv yuk nazariyasi, bosqichma-bosqich ishora protokoli, explain-plan tahlili va texno-pedagogik arxitektura asosida ishlab chiqildi. Mazkur nazariy-uslubiy asoslar keyingi boblarda metodika va tajriba-sinov ishlarini ishlab chiqish uchun metodologik poydevor vazifasini bajaradi.

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SUN'IY INTELLEKT YORDAMIDA FIZIKA FANINI O'QITISH: TRANSFORMATSIYA, MUAMMOLAR VA PEDAGOGIK STRATEGIYALAR**Razzoqov Ilhom Dovranovich,**razzokov.id@qarshidu.uz, Qarshi davlat universiteti, ORCID: 0009-0000-2969-3945

Annotatsiya. Ushbu maqola fizika fanini o'qitishda sun'iy intellekt (SI) texnologiyalarining integratsiyasini kompleks tahlil qiladi. Tadqiqot adaptiv o'qitish tizimlari, generativ chatbotlar (masalan, ChatGPT), SI asosidagi virtual laboratoriyalar va avtomatik baholash vositalarining pedagogik imkoniyatlarini o'rganadi. So'nggi adabiyotlar tahlili shuni ko'rsatadiki, SI vositalari o'qitishni individuallashtirish, murakkab fizik tushunchalarni vizualizatsiya qilish va talabalarga tezkor fikr-mulohaza berishda yuqori samaradorlikka ega. Biroq, tadqiqotlar SI dan foydalanishda talabalarning tanqidiy fikrlash qobiliyatining pasayishi, ma'lumotlar maxfiyligi va o'qituvchi rolining o'zgarishi kabi jiddiy muammolarni ham aniqlagan. Xulosa qilib aytganda, sun'iy intellekt fizika ta'limini tubdan o'zgartirish potentsialiga ega, ammo bu transformatsiya pedagogik nazorat va metodik asoslangan yondashuvni talab qiladi.

Kalit so'zlar: sun'iy intellekt, fizika ta'limi, ChatGPT, adaptiv o'qitish, generativ SI, virtual laboratoriyalar, pedagogik transformatsiya, SI savodxonligi.

So'nggi yillarda sun'iy intellekt (SI) texnologiyalari ta'lim sohasida, xususan, aniq fanlarni o'qitishda tobora muhim rol o'ynay boshladi. Ayniqsa, OpenAI kompaniyasining ChatGPT kabi generativ till modellarining paydo bo'lishi fizika ta'limida yangi imkoniyatlar va jiddiy muammolarni keltirib chiqardi. Fizika – mavhum tushunchalar, matematik modellashtirish va eksperimental tekshiruvga asoslangan fan sifatida – SI vositalaridan foydalanish uchun o'ziga xos maydon hisoblanadi.

An'anaviy fizika ta'limida o'qituvchi oldida turgan asosiy muammolardan biri – talabalarning bilim darajasi, qabul qilish tezligi va oldingi tayyorgarligidagi katta farqlardir. SI asosidagi adaptiv tizimlar bu muammoni hal qilishda muhim vositaga aylanishi mumkin. Shu bilan birga, so'nggi tadqiqotlar shuni ko'rsatadiki, talabalarning ChatGPT kabi vositalardan foydalanishi ularning mustaqil muammo yechish qobiliyatlariga salbiy ta'sir ko'rsatishi mumkin.

Ushbu maqolaning maqsadi – fizika fanini o'qitishda sun'iy intellekt texnologiyalarini qo'llashning hozirgi holatini, imkoniyatlarini va cheklovlarini kompleks tahlil qilish, shuningdek, SI vositalaridan pedagogik jihatdan asoslangan holda foydalanish bo'yicha tavsiyalar ishlab chiqish.

Sun'iy intellekt va ta'lim sohasidagi asosiy tadqiqotlar. Holmes va boshqalar (2019) tomonidan olib borilgan tadqiqot SI ning ta'limdagi uchta asosiy funksiyasini aniqlaydi: adaptiv o'qitish, ma'lumotlarni tahlil qilish asosida bashoratlash va interaktiv muloqot. Roll va Wylie (2016) esa SI ta'limdagi evolyutsiyasini to'rt bosqichga ajratadi: asboblarni, repetitorlarni, hamkor va nazoratchi.

Luckin va boshqalar (2016) ta'kidlaganidek, SI ning eng katta afzalligi – uning talabaning bilim holatini aniq diagnostika qilish va shunga mos keladigan o'quv traektoriyasini taklif qilish imkoniyatidir. Bu, ayniqsa, fizika kabi ketma-ket mantiqiy tuzilgan fanlar uchun muhim.

Fizika ta'limida generativ SI vositalarining qo'llanilishi. So'nggi ikki yilda generativ SI vositalarining fizika ta'limida qo'llanilishi bo'yicha bir qator tadqiqotlar olib borildi. Elson va boshqalar (2025) tomonidan o'tkazilgan tadqiqotda 119 nafar bakalavriat talabalari kvant fizikasi masalalarini yechishda ChatGPT dan foydalanganlar. Tadqiqot natijalari shuni ko'rsatdiki, ChatGPT murakkab fizik masalalarni, jumladan, bir o'lchamli kvant garmonik ossillyatorning xos funksiyalari bilan bog'liq muammolarni hal qilishda yuqori darajadagi kompetensiyani namoyish etgan.

Biroq, mualliflar muhim bir muammoni aniqladilar: talabalar ChatGPT dan "tayyor javob" olish vositasi sifatida foydalanishga moyil bo'lib, bu ularning o'z fikrlash jarayonlarini rivojlantirishga xalaqit beradi. Ushbu kuzatuv boshqa tadqiqotchilar tomonidan ham tasdiqlangan –

Küchemann va boshqalar (2023) ChatGPT dan foydalanayotgan talabalarda tanqidiy fikrlash va muammoni mustaqil yechish qobiliyatlarining pasayishini qayd etganlar.

SI asosidagi vizualizatsiya va simulyatsiyalar. de Souza va boshqalar (2024) tomonidan olib borilgan tadqiqotda o'rta maktab o'quvchilarining umumiy nisbiylik nazariyasi haqidagi tushunchalarini baholashda SI tomonidan yaratilgan tasvirlardan foydalanilgan. Tadqiqotda 10 nafar o'quvchi ishtirok etgan. Natijalar shuni ko'rsatdiki, nisbiylik tushunchasini aniqroq tushungan o'quvchilar o'z promptlarida makon-vaqt deformatsiyasi kabi markaziy tushunchalarga ko'proq e'tibor qaratganlar. Aksincha, tushunchasi zaifroq bo'lgan o'quvchilar chet mavzularga ko'proq murojaat qilganlar.

Virtual laboratoriyalar va simulyatsiyalar. PhET Interactive Simulations (2023) keng qamrovli tadqiqotlar shuni ko'rsatadiki, SI asosidagi virtual laboratoriyalar an'anaviy laboratoriya ishlariga qaraganda ayrim jihatlaridan ustunlikka ega. Xususan, virtual muhitda parametrlarni keng diapazonda o'zgartirish, tez vaqt oralig'idagi jarayonlarni sekinlashtirib ko'rsatish va xavfli tajribalarni xavfsiz tarzda o'tkazish imkoniyatlari mavjud.

Amaliy tadqiqotlarning meta-tahlili– ChatGPT va boshqa SI vositalarining fizika ta'limidagi samaradorligini o'rganuvchi empirik tadqiqotlarning natijalari umumlashtirildi.

Pedagogik modellarni solishtirish– SI vositalaridan foydalanadigan va foydalanmaydigan o'qitish metodikalarining qiyosiy tahlili amalga oshirildi.

Adaptiv o'qitish tizimlarining samaradorligi. Adabiyotlar tahlili shuni ko'rsatadiki, SI asosidagi adaptiv o'qitish tizimlari fizikani o'zlashtirishda an'anaviy usullarga nisbatan o'rtacha 15-20% samaradorlikka ega. Eng katta farq individual o'quv traektoriyasini shakllantirish va real vaqt rejimida fikr-mulohaza berish imkoniyatlarida namoyon bo'ladi.

Shu bilan birga, adaptiv tizimlarning samaradorligi uchun asosiy shart – ularning pedagogik jihatdan to'g'ri sozlanganligidir. Faqat algoritmik jihatdan mukammal bo'lgan, ammo metodik asosga ega bo'lmagan tizimlar kutilgan natijani bermaydi.

ChatGPT va generativ SI: imkoniyatlar va tahdidlar. Elson va boshqalar (2025) tadqiqotining eng muhim natijalaridan biri shundaki, ChatGPT fizika masalalarini yechishda “mutaxassis fizik darajasida” ishlashga qodir. Xususan, Force Concept Inventory (FCI) testidagi savollarga javob berishda yuqori natijalarni ko'rsatgan.

Polverini (2023) ta'kidlaganidek, “katta till modellari qanday ishlashini tushunish ularning fizika ta'limida qanday qo'llanilishi kerakligini belgilaydi”. Talabalar SI vositalarining cheklovlarini – ularning ba'zan noto'g'ri yoki “galyutsinatsiya” qiluvchi javoblar berishi mumkinligini – bilishlari kerak.

SI orqali vizualizatsiya: nisbiylik nazariyasi misolida. de Souza va boshqalar (2024) tadqiqoti SI orqali yaratilgan tasvirlar o'quvchilarning tushunchalarini baholash uchun samarali vosita bo'lishi mumkinligini ko'rsatdi. Tadqiqotda qatnashgan o'quvchilar “nisbiylik” tushunchasini SI chatboti yordamida tasvirlashlari so'ralgan.

Natijalar shuni ko'rsatdiki:

Nisbiylik tushunchasini aniq tushungan o'quvchilar o'z promptlarida “makon-vaqt deformatsiyasi”, “massaning egilishi” kabi markaziy tushunchalardan foydalanishganlar.

Tushunchasi zaifroq bo'lgan o'quvchilar esa “soatlar”, “yorug'lik”, “tezlik” kabi chet mavzularga murojaat qilishgan.

Prompt yozish qobiliyati va tushunish chuqurligi o'rtasida to'g'ri korrelyatsiya aniqlangan.

Ushbu natija muhim pedagogik xulosaga olib keladi: SI vositalaridan samarali foydalanish uchun o'quvchilarga prompt yozish bo'yicha alohida ko'nikmalarni shakllantirish kerak.

Virtual laboratoriyalar va simulyatsiyalar tahlili. Virtual laboratoriyalarning an'anaviy laboratoriyalarga nisbatan afzalliklari va kamchiliklari quyidagi jadvalda keltirilgan:

Adabiyotlar tahlili shuni ko'rsatadiki, optimal yondashuv – virtual va an'anaviy laboratoriyalarning kombinatsiyasi. Murakkab yoki xavfli tajribalar birinchi navbatda virtual muhitda o'rganiladi, so'ngra asosiy tajribalar an'anaviy laboratoriyada bajariladi.

Amaliy tavsiyalar: SI dan pedagogik maqsadlarda foydalanish. Adabiyotlar tahlili va amaliy tajribalar asosida fizika o'qitishda SI vositalaridan foydalanish bo'yicha quyidagi tavsiyalar ishlab chiqilgan:

1. Boshlang'ich bosqichda SI dan foydalanishni cheklash

2. Talabalar asosiy fizik tushunchalar va masala yechish usullarini avval an'anaviy usulda o'zlashtirib olishlari kerak. SI vositalari faqat bilimlar mustahkamlangan bosqichda joriy etilishi tavsiya etiladi.

3. Prompt yozish ko'nikmalarini o'rgatish

4. Talabalar SI vositalariga aniq, batafsil va tizimli promptlar yozishni o'rganishlari kerak. Bu ularning o'z tushunchalarini aniq ifodalash qobiliyatini rivojlantiradi.

Talabalarni SI javoblarini tanqidiy tahlil qilishga, xatolarni aniqlashga va javobni o'z so'zlari bilan qayta ifodalashga o'rgatish kerak.

SI asosidagi baholashda ehtiyotkorlik. SI vositalari avtomatik baholash va fikr-mulohaza berishda samarali bo'lsa-da, yakuniy baholashda talabaning SI dan mustaqil ishlash qobiliyatini tekshirish muhim.

O'qituvchilarning SI savodxonligini oshirish. O'qituvchilar SI vositalarining imkoniyatlari va cheklovlarini bilishlari, ularni o'z pedagogik strategiyalariga integratsiya qilish ko'nikmalariga ega bo'lishlari kerak.

Ma'lumotlar maxfiyligi va axloqiy masalalar. Williams va boshqalar (2023) ta'kidlaganidek, generativ chatbotlardan oliy ta'limda foydalanish jiddiy axloqiy muammolarni keltirib chiqaradi. Talabalarining ma'lumotlarining xavfsizligi, SI tomonidan berilgan javoblarning haqiqiyliigi va mualliflik huquqi masalalari hal qilinmagan.

Ko'pgina SI tizimlari, ayniqsa chuqur o'rganishga asoslanganlari, o'z qarorlarini tushuntirish qobiliyatiga ega emas. Bu ularning fizika ta'limida qo'llanilishiga cheklov qo'yadi, chunki talaba nafaqat natijani, balki uning qanday olinganligini ham tushunishi kerak.

O'qituvchi rolining o'zgarishi. An'anaviy fizika o'qituvchisining roli – bilim manbai va masala yechuvchi. SI vositalari bu funksiyalarning bir qismini avtomatlashtirishi bilan o'qituvchi yangi rolni – "SI foydalanuvchisini o'rgatuvchi" va "metakognitiv yo'l ko'rsatuvchi" rolini o'zlashtirishi kerak. Bu ko'plab o'qituvchilar uchun jiddiy kasbiy rivojlanish ehtiyojini keltirib chiqaradi.

Xulosa va takliflar. Sun'iy intellekt fizika fanini o'qitishda inqilobiy o'zgarishlar qilish potentsialiga ega. Adaptiv tizimlar, generativ chatbotlar va virtual laboratoriyalar o'qitishni individuallashtirish, vizualizatsiya qilish va interaktiv qilish imkonini beradi.

Biroq, so'nggi tadqiqotlar shuni ko'rsatadiki, SI vositalaridan pedagogik jihatdan asoslanmagan holda foydalanish talabalarining mustaqil fikrlash va muammo yechish qobiliyatlariga salbiy ta'sir ko'rsatishi mumkin. SI o'qituvchini almashtiruvchi emas, balki uning faoliyatini kuchaytiruvchi vosita sifatida qaralishi kerak.

Kelgusidagi tadqiqotlar quyidagi yo'nalishlarga e'tibor qaratishi maqsadga muvofiq:

SI vositalaridan foydalanishning uzoq muddatli ta'sirini o'rganuvchi ilmiy tadqiqotlar

Fizikaning turli sohalari (klassik mexanika, kvant fizikasi, termodinamika) uchun maxsus ishlanmagan SI vositalarini yaratish

SI savodxonligini o'qituvchilar tayyorlash dasturlariga integratsiya qilish metodikasi

SI vositalaridan foydalanishda talabalarining metakognitiv faolligini oshiruvchi pedagogik strategiyalar

Fizika ta'limining kelajagi – sun'iy intellekt va inson aqlining sinergiyasida. Bu sinergiyani to'g'ri tashkil etish bugungi fizika o'qituvchilari va tadqiqotchilarining asosiy vazifasidir.

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SUN'IY INTELLEKT VA MA'LUMOT TAHLILINI O'QITISH ASOSLARI
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Annotatsiya

Ushbu maqolada sun'iy intellekt va ma'lumot tahlili fanlarini o'qitishning nazariy hamda amaliy asoslari yoritilgan. Raqamli iqtisodiyot sharoitida ta'lim tizimida ma'lumotlar bilan ishlash ko'nikmalarini shakllantirish zarurati tahlil qilinib, SI asosida qurilgan o'qitish metodologiyalari, vositalar va zamonaviy yondashuvlar ko'rib chiqilgan. O'zbekiston ta'lim tizimida ushbu yo'nalishni rivojlantirish bo'yicha takliflar ilgari surilgan.

Raqamli transformatsiya davri inson faoliyatining barcha sohalarini - iqtisodiyot, sog'liqni saqlash, ta'lim va davlat boshqaruvini — tubdan o'zgartirmoqda. O'zbekiston Respublikasi Prezidentining 2020-yil 5-oktyabrdagi "Raqamli O'zbekiston — 2030" strategiyasini tasdiqlash to'g'risidagi PF-6079-sonli Farmoni mamlakatimizda sun'iy intellekt va raqamli texnologiyalar sohasida malakali mutaxassislar tayyorlashni davlat siyosatining ustuvor yo'nalishiga aylantirdi [1].

Mazkur maqolada sun'iy intellekt va ma'lumot tahlilini o'qitishning ilmiy-pedagogik asoslari, zamonaviy metodologiyalar, amaliy vositalar va O'zbekiston ta'lim tizimidagi istiqbollar kompleks tarzda tahlil qilinadi.

Mavzuning ilmiy asoslarini shakllantirish maqsadida bir qator mahalliy va xorijiy tadqiqotlar o'rganildi. Professor M.M.Aripovning "Axborot texnologiyalari" o'quv qo'llanmasida ta'kidlanishicha, "Sun'iy intellektni o'qitishda nazariy bilim va amaliy ko'nikmalar uyg'unligi asosiy shart hisoblanadi"[4]. Bu fikr hozirgi kunda Data Science fanini o'qitishdagi fundamental tamoyil sifatida qabul qilingan.

U.Sh.Begimqulovning monografiyasida pedagogik jarayonlarni axborotlashtirish nazariyasi chuqur yoritilgan bo'lib, muallif raqamli vositalarning o'qituvchi va talaba o'rtasidagi o'zaro ta'sirini yangi bosqichga ko'tarishini asoslab bergan[3]. Bu g'oya SI va ma'lumot tahlilini o'qitishda ham o'z aksini topadi: intellektual o'qitish tizimlari talabaning individual sur'atini hisobga oladi va bilim bo'shliqlarini real vaqtda bartaraf etadi.

Xalqaro ilmiy adabiyotlarda YUNESKO tomonidan tayyorlangan "AI and Education" hisobotida ta'lim tizimida sun'iy intellektni qo'llashda "algoritmik shaffoflik" va "raqamli mas'uliyat" tamoyillariga alohida e'tibor qaratish lozimligi uqtirilgan [5]. Bu tamoyillar ma'lumot tahlilini o'qitishda ham muhim ahloqiy qoida sifatida qo'llanilishi lozim.

Ma'lumot tahlili (Data Analysis) — bu katta hajmdagi xom ma'lumotlardan foydali axborot, qonuniyat va prognozlar ajratib olish jarayonidir. Ushbu soha statistika, matematika, dasturlash va sohaviy bilimlarni o'zida mujassam etuvchi fanlararo (interdisciplinary) yo'nalish hisoblanadi.

Ma'lumot tahlilining asosiy bosqichlari quyidagilardan iborat:

- Ma'lumotlarni yig'ish (Data Collection): Turli manbalardan — sensorlar, so'rovnomalar, ma'lumotlar bazalari va veb-sahifalardan ma'lumot olish.

- Ma'lumotlarni tozalash (Data Cleaning): Noto'liq, takroriy yoki noto'g'ri ma'lumotlarni bartaraf etish.

- Tadqiqiy tahlil (Exploratory Data Analysis - EDA): Ma'lumotlarning tuzilishi, taqsimoti va bog'liqliklarini vizuallashtirish orqali o'rganish.

- Modellash (Modeling): Mashina o'qitishi algoritmlaridan foydalanib, prognoz yoki tasniflash modellarini qurish.

- Natijalarni talqin qilish va taqdim etish: Murakkab natijalarni sodda grafiklar va hisobotlar orqali ifodalash.

Sun'iy intellekt va ma'lumot tahlilini o'qitishning pedagogik modeli

Sun'iy intellekt va ma'lumot tahlilini o'qitishda an'anaviy ma'ruzabop yondashuv yetarli emas. Bu soha o'z tabiatiga ko'ra amaliy va eksperimental bo'lib, "Amaliyot orqali o'rganish" (Project-Based Learning) metodologiyasi eng samarali natija beradi. Talaba faqat algoritm haqida o'qib o'rganish orqali emas, balki uni o'zi qo'llab ko'rish, natijalarini tahlil qilish va xatolarini tushunish orqali chinakam bilim oladi.

Samarali o'qitish modelida quyidagi bosqichlar ketma-ketligi tavsiya etiladi: nazariy asos (algoritm mantig'ini tushuntirish) → kod namunasi (demo) → mustaqil amaliy topshiriq → loyiha (real ma'lumotlar bilan ishlash) → taqdimot va muhokama. Bu siklik jarayon talabada "Ma'lumotli fikrlash" (Data Literacy) ko'nikmasini shakllantiradi.

O'qitishda qo'llaniladigan zamonaviy vositalar va platformalar

Hozirgi kunda sun'iy intellekt va ma'lumot tahlilini o'qitishda foydalaniladigan vositalar soni keskin ko'paygan. Ular orasida dasturlash tillari va interaktiv muhitlar alohida o'rin tutadi.

Python dasturlash tili ma'lumot tahlilida eng keng tarqalgan til hisoblanadi. Buning asosiy sabablari:

- Pandas, NumPy kutubxonalari orqali ma'lumotlarni tez va oson qayta ishlash imkoniyati;
- Matplotlib va Seaborn kutubxonalari yordamida professional vizualizatsiya yaratish;
- Scikit-learn, TensorFlow va PyTorch vositalari orqali mashina o'qitishi modellarini qurish;
- Jupyter Notebook muhiti — kod, natija va izohni bir joyda birlashtiruvchi interaktiv platforma.

Bundan tashqari, "Kaggle" platformasi talabalar uchun real ma'lumotlar to'plami (dataset) va musobaqalar bazasi sifatida xizmat qilib, amaliy ko'nikmalarni rivojlantirishga yordam beradi. Google Colab esa internet orqali bepul GPU resurslariga kirish imkonini beruvchi bulutli muhit sifatida ayniqsa, imkoniyati cheklangan hududlarda ta'lim samaradorligini oshiradi.

Sun'iy intellekt yordamida shaxsiylashtirilgan o'qitish

Ma'lumot tahlilini o'qitishda o'zining eng yuqori qo'llanilishini Sun'iy intellekt "Adaptiv o'qitish" tizimlari orqali topadi. Bunday tizimlar talabaning har bir testdagi javoblarini, kod yozish tezligi va xatolarini tahlil qilib, unga individual o'quv yo'li taklif qiladi.

Masalan, bir talaba statistika bo'limida qiynalayotgan bo'lsa, sun'iy intellekt tizimi unga avtomatik ravishda qo'shimcha mashqlar, video darslar va osonroq tushuntirishlar taklif qiladi. Boshqa talaba esa allaqachon shu mavzuni bilsa, uni to'g'ridan-to'g'ri keyingi murakkab mavzuga yo'naltiradi. Bu jarayon o'qituvchining har bir talabaga alohida e'tibor berish yuki va vaqt xarajatlarini sezilarli darajada kamaytirib, sifat va qamrovni bir vaqtning o'zida oshiradi.

Sun'iy intellekt va ma'lumot tahlilini o'qitishning samaradorligini o'lchash maqsadida o'tkazilgan pedagogik tadqiqot doirasida axborot texnologiyalari yo'nalishi talabalari ikki guruhga bo'linib, "Haqiqiy turar-joy bozori narxlarini prognozlash" loyihasi ustida ish olib borildi.

Nazorat guruhi ma'lumotlarni qayta ishlashda faqat an'anaviy statistik usullar (o'rta arifmetik, dispersiya tahlili) qo'lladi. Eksperimental guruh esa Python dasturlash tili va Scikit-learn kutubxonasi yordamida Chiziqli regressiya (Linear Regression) va Qaror daraxti (Decision Tree) algoritmlaridan foydalandi.

Parametrlar	An'anaviy usul	Sun'iy intellekt yordamida
Prognoz aniqligi (R^2)	0.61	0.87
Tahlil vaqti (daqiqqa)	120	38
Talabalar motivatsiyasi (10 ball)	6.2 ball	9.1 ball
Mustaqil loyiha bajarganlar (%)	34%	78%

1-jadval. Pedagogik eksperiment natijalarining qiyosiy tahlili

Jadvalda keltirilgan natijalar shuni ko'rsatadiki, sun'iy intellekt va mashina o'qitishi algoritmlarini o'quv jarayoniga integratsiya qilish nafaqat texnik natijani yaxshilaydi, balki talabalarining mavzuga bo'lgan qiziqishi va mustaqil izlanish faolligini ham sezilarli darajada oshiradi. Bu esa "Ma'lumotlarga asoslangan fikrlash" ko'nikmasining shaxsiy va kasbiy rivojlanishda tub o'zgarishlar olib kelishini tasdiqlaydi.

Sun'iy intellekt va ma'lumot tahlilini o'qitish XXI asrda kasbiy ta'limning ajralmas qismiga aylandi. Ushbu maqolada ko'rib chiqilgan ilmiy-pedagogik tahlil quyidagi muhim xulosalarga olib keladi: birinchidan, ma'lumot tahlilini faqat nazariy ko'rinishda emas, balki real loyihalar orqali o'rgatish sezilarli darajada samarali; ikkinchidan, Python va zamonaviy ML kutubxonalari ta'lim jarayonini iqtisodiy jihatdan ham samarali qiladi; uchinchidan, adaptiv o'qitish tizimlari talabaning individual sur'atini hisobga olish imkonini beradi.

O'zbekiston ta'lim tizimida ushbu sohani rivojlantirish uchun quyidagi takliflar ilgari suriladi:

- O'zbek tilidagi ochiq ma'lumotlar to'plamlari (open datasets) va o'quv materiallari platformasini yaratish.

- O'qituvchilarni qayta tayyorlash dasturlari doirasida Python va sun'iy intellekt asoslarini o'rgatuvchi maxsus modullarni joriy etish.

- Maktablarda "Ma'lumotlar dunyosi" to'garaklarini tashkil etib, yosh avlodni erta yoshdan ma'lumotli fikrlashga o'rgatish.

- Kaggle, Coursera va edX kabi xalqaro platforma bilan hamkorlikni kuchaytirish orqali talabalarining global musobaqalarda ishtirokini ta'minlash.

Ushbu takliflar izchil amalga oshirilsa, O'zbekiston 2030-yilga kelib mintaqada sun'iy intellekt va ma'lumot tahlili sohasidagi yetakchi ta'lim markazlaridan biriga aylanishi mumkin.

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МАКТАБГАЧА ТАЪЛИМДА СУНЬИЙ ИНТЕЛЛЕКТ ТЕХНОЛОГИЯЛАРИНИ ҚЎЛЛАШ

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Аннотация. Мақолада мактабгача таълим тизимида сунъий интеллект технологияларини қўллашнинг имкониятлари баён этилган. Шунингдек, интеллектуал таълим платформалари, интерактив ўйинлар, виртуал ассистентлар ва адаптив таълим технологияларининг болалар ривожланишига таъсири ёритилган бўлиб, бу таълим-тарбия жараёнида сунъий интеллект технологиясидан мазмунли фойдаланиш ва таълим-тарбия самарадорлигини ошириш имкониятини беради.

Калит сўзлар: сунъий интеллект, мактабгача таълим, рақамли технологиялар, адаптив таълим, интеллектуал тизимлар, инновацион таълим.

Бугунги кунда рақамли технологияларнинг жадал ривожланиши таълим соҳасида ҳам катта ўзгаришларни юзага келтирмоқда. Айниқса, сунъий интеллект технологиялари таълим жараёнини янада самарали ташкил қилиш, болаларнинг индивидуал қобилятларини

аниқлаш ва уларнинг қизиқишларига мос таълим муҳитини шакллантириш имкониятини бермоқда.

Ўзбекистон Республикаси “Таълим тўғрисида”ги Қонунининг 7-моддасида таълим турлари санаб ўтилиб, унинг биринчи тури – мактабгача таълим ва тарбия эканлиги таъкидланган. Шунингдек, 8-моддасида: “Мактабгача таълим ва тарбия болаларни ўқитиш ва тарбиялашга, уларни интеллектуал, маънавий-ахлоқий, этик, эстетик ва жисмоний жиҳатдан ривожлантиришга, шунингдек болаларни умумий ўрта таълимга тайёрлашга қаратилган таълим туридир”⁸, - дейилган.

Ўзбекистон Республикаси Президентининг “2017-2021 йилларда мактабгача таълим тизимини янада такомиллаштириш чора-тадбирлари тўғрисида”ги қарорига “... мактабгача таълим сифатини ошириш, мактабгача таълим муассасаларида болаларни мактабга сифатли тайёрлашни тубдан яхшилаш, таълим-тарбия жараёнига жаҳон амалиётида кенг қўлланиладиган замонавий таълим дастурлари ва технологияларини жорий этиш”⁹ - вазифалари белгиланган.

Юқорида баён қилинган далиллардан кўриниб турибдики, мактабгача таълим тизимига инновацион технология сифатида сунъий интеллект технологиясини татбиқ этиш, болаларни умумий ўрта таълимга компьютер саводхонлиги билан тайёрлаш, уларни компьютер билан элементар тарзда фойдаланишга ўргатиш ва мактаб таълимига тайёрлаш бугунги куннинг долзарб масалалардан бири эканлигини кўрсатади[3].

Мактабгача таълим тизимида боланинг интеллектуал, ижтимоий ва психологик ривожланиши муҳим аҳамиятга эга. Шу боис замонавий ахборот-коммуникация технологияларидан фойдаланиш орқали таълим сифатини ошириш долзарб вазифалардан бири ҳисобланади. Сунъий интеллект технологиялари болаларнинг ёши ва психофизиологик хусусиятларини ҳисобга олган ҳолда индивидуал ёндашув асосида таълим бериш имконини яратади. технологиялари мактабгача таълим жараёнини самарали ташкил қилишда муҳим аҳамиятга эга. Интерактив платформалар, виртуал ассистентлар ва адаптив таълим технологиялари болаларнинг қизиқиши ва фаоллигини ошириши аниқланди. Шунингдек, таълимий ўйинлар болаларнинг мантикий фикрлаш ва ижодий қобилиятларини ривожлантиришга ижобий таъсир кўрсатиши кузатилди. Лекин, бу жараёнда техник инфратузилманинг етарли эмаслиги, педагог кадрларнинг рақамли компетенцияларини ривожлантириш зарурати ва ахборот хавфсизлиги масалалари долзарб бўлиб қолмоқда.

Сунъий интеллект — инсон тафаккурини тақлид қилувчи ва маълумотларни таҳлил қилиш орқали қарор қабул қилиш имкониятига эга бўлган технологиялар мажмуасидир. Мактабгача таълим тизимида ушбу технологиялардан фойдаланиш таълим жараёнини интерфаол ва қизиқарли ташкил этишга хизмат қилади.[4].

1.Интерактив таълим платформалари

Мактабгача таълим муассасаларида сунъий интеллект асосида ишловчи интерактив платформалар болаларнинг билим олиш жараёнини қизиқарли ва самарали ташкил этади. Бундай платформалар боланинг фаоллиги, қизиқиши ва билим даражасини таҳлил қилиб, унга мос топшириқлар тақдим этади.Интерактив мультимедиа материаллари, овозли ёрдамчилар ва анимацион дастурлар болаларнинг диққатини жалб қилиб, уларнинг тезроқ ўзлаштиришига ёрдам беради.

2. Адаптив таълим технологиялари

Адаптив таълим тизимлари ҳар бир боланинг индивидуал қобилияти ва ўқув суръатини ҳисобга олган ҳолда таълим беради. Агар бола муайян мавзуда қийналса, тизим кўшимча машқлар ва тушунтиришлар таклиф қилади.Бу эса болаларнинг билим даражасини

⁸ Ўзбекистон Республикасининг “Таълим тўғрисида”ги Қонуни // Қонун ҳужжатлари маълумотлари миллий базаси, 24.09.2020 й., 03/20/637/1313-сон

⁹ Ўзбекистон Республикаси Президентининг 2016 йил 29 декабрдаги "2017-2021 йилларда мактабгача таълим тизимини янада такомиллаштириш чора-тадбирлари тўғрисида"ги ПҚ-2707-сон қарори. - Ўзбекистон Республикаси қонун ҳужжатлари тўплами, 2017 й., 1-сон, 11-модда, 35-сон, 923-модда; Қонун ҳужжатлари маълумотлари миллий базаси, 31.07.2018 й., 06/18/5483/1594-сон.

босқичма-босқич ривожлантиришга хизмат қилади. Шу билан бирга, тарбиячилар учун ҳам болаларнинг ривожланиш даражасини мониторинг қилиш имкониятини яратади.

3. Виртуал ассистентлар ва робототехника

Сўнгги йилларда мактабгача таълимда робототехника ва виртуал ассистентлардан фойдаланиш кенгаймоқда. Интеллектуал роботлар болалар билан мулоқот қилиб, уларга ҳарфлар, рақамлар, шакллар ва тилларни ўргатишда ёрдам беради. Виртуал ассистентлар эса болаларнинг саволларига жавоб бериш, таълимий ўйинларни бошқариш ва машғулотларни ташкил қилиш вазифаларини бажаради. Бу жараён болаларнинг мантикий фикрлаш ва ижодкорлик қобилиятини ривожлантиришга хизмат қилади.

4. Таълимий ўйинлар ва gamification

Сунъий интеллект асосида ишловчи таълимий ўйинлар болаларнинг қизиқишини оширишда муҳим аҳамиятга эга. Ўйин технологиялари орқали болалар рақамлар, ҳарфлар, ранглар ва табиат ҳақидаги билимларни осон ўзлаштиради. Gamification усули таълим жараёнини қизиқарли ташкил этиб, болаларнинг мустақил фикрлаши ва муаммоларни ҳал қилиш қобилиятини шакллантиради.

5. Таълим жараёнини таҳлил қилиш

Сунъий интеллект технологиялари болаларнинг ўқув фаолияти ҳақидаги маълумотларни таҳлил қилиш имконини беради. Бу орқали тарбиячилар ва ота-оналар боланинг ривожланиш даражаси, қизиқишлари ва қобилиятлари ҳақида аниқ маълумот олишлари мумкин. Таҳлил натижалари асосида индивидуал таълим дастурлари ишлаб чиқилиб, болаларнинг интеллектуал салоҳиятини ривожлантиришга эътибор қаратилади.

Сунъий интеллект технологияларининг афзалликлари

Мактабгача таълимда сунъий интеллект технологияларини қўллаш қуйидаги афзалликларни таъминлайди:

- болаларнинг таълимга қизиқишини оширади;
- индивидуал таълим имкониятларини яратади;
- таълим жараёнини интерфаол ташкил этади;
- болаларнинг мантикий фикрлашини ривожлантиради;
- рақамли кўникмаларни шакллантиради;
- тарбиячиларнинг иш фаолиятини енгиллаштиради.

Лекин, бу жараёнда қуйидаги муаммолар мавжуд:

- ушбу технологияларни жорий этишда техник жиҳозларнинг етарли эмаслиги;
- интернет тармоғининг чекланганлиги;
- педагог кадрларнинг рақамли компетенцияларини ошириш зарурати.

Демак, сунъий интеллект технологиялари мактабгача таълим тизимини модернизация қилишда муҳим аҳамият касб этмоқда. Ушбу технологиялар болаларнинг интеллектуал ва ижодий қобилиятларини ривожлантириш, таълим жараёнини индивидуаллаштириш ва таълим сифатини ошириш имкониятини яратади. Келажакда мактабгача таълим муассасаларида интеллектуал платформалар, робототехника ва адаптив таълим тизимларидан кенг фойдаланиш орқали рақамли таълим муҳитини янада ривожлантириш мумкин. Бу эса баркамол ва рақобатбардош авлодни тарбиялашда муҳим омил бўлиб хизмат қилади.

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TA'LIMDA SUN'IY INTELLEKT TEXNOLOGIYALARINING AHAMIYATI

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Annotatsiya. Maqolada ta'lim tizimida sun'iy intellekt texnologiyalarining qo'llanilishi, uning zamonaviy ta'limdagi o'rni, afzalliklari va istiqbollari haqida ma'lumot berilgan. Shuningdek, sun'iy intellekt yordamida individual ta'limni rivojlantirish, masofaviy ta'lim samaradorligini oshirish, ta'lim sifatini nazorat qilish hamda raqamli platformalarning imkoniyatlari yoritilgan.

Kalit so'zlar: sun'iy intellekt, ta'lim texnologiyalari, raqamli ta'lim, innovatsion texnologiyalar, Big Data, masofaviy ta'lim, elektron platforma.

Respublikamizda barkamol avlodni tarbiyalash, yoshlarning intellektual salohiyatini ro'yobga chiqarish, ularni har tomonlama rivojlangan shaxs etib voyaga yetkazish bugungi kunning asosiy vazifalari sirasiga kiradi. Ta'lim jarayonida sun'iy intellekt texnologiyasidan foydalanish bugungi kunning asosiy vazifalari qatoriga kiradi.

O'zbekiston Respublikasi "Ta'lim to'g'risida"gi Qonunining 5-moddasida "Ta'lim tashkilotlarida innovatsion faoliyatni qo'llab-quvvatlash va o'quv dasturlarini innovatsion texnologiyalarni qo'llagan holda amalga oshirish", 46-moddasida esa pedagog xodimlarning majburiyatlari sifatida "Axborot-kommunikatsiya texnologiyalaridan, o'qitish va tarbiyaning ilg'or hamda innovatsion shakllari va usullaridan foydalanishi"¹⁰, - lozimligi ta'kidlangan.

Shuningdek, 36-modda - Ta'lim sohasidagi eksperimental va innovatsion faoliyat bandida: "Ta'lim sohasidagi eksperimental va innovatsion faoliyat ta'limni modernizatsiya qilish maqsadida amalga oshiriladi hamda yangi ta'lim texnologiyalari va resurslarini ishlab chiqishga, ularni sinovdan o'tkazishga hamda ta'lim jarayoniga joriy etishga qaratilgan"¹¹, - deyilgan.

O'zbekiston Respublikasi Prezidentining 2025 йил 22 октябрдаги "Sun'iy intellekt texnologiyalarini yanada rivojlantirishga oid qo'shimcha chora-tadbirlar to'g'risida" PF-189-son farmonida "Sun'iy intellekt texnologiyalarini 2030-yilga qadar rivojlantirish strategiyasiga muvofiq mamlakatimizda zamonaviy texnologiyalarning jadal rivojlanishini qo'llab-quvvatlash, shuningdek, sun'iy intellektni keng joriy qilish uchun yanada qulay sharoitlar yaratish, ushbu yo'nalishga qo'shimcha investitsiyalarni jalb qilish hamda malakali mutaxassislarni tayyorlash tizimini yanada takomillashtirish buyicha bir qator vazifalar belgilangan."¹²

Hozirgi davrda raqamli texnologiyalar inson hayotining barcha jabhalariga kirib kelmoqda. Ayniqsa, ta'lim tizimida axborot-kommunikatsiya texnologiyalarining rivojlanishi yangi imkoniyatlarni yuzaga keltirdi. Sun'iy intellekt texnologiyalarining paydo bo'lishi esa ta'lim tizimini yanada takomillashtirishga xizmat qilmoqda.

Sun'iy intellekt — bu kompyuter tizimlarining inson tafakkuriga xos bo'lgan fikrlash, tahlil qilish, o'rganish va qaror qabul qilish jarayonlarini amalga oshirish qobiliyatidir. Bugungi kunda sun'iy intellekt texnologiyalari rivojlangan davlatlar ta'lim tizimida keng qo'llanilmoqda. Ushbu texnologiyalar ta'lim jarayonining samaradorligini oshirish, o'quvchilarning bilim darajasini aniqlash hamda individual yondashuvni shakllantirishda muhim vosita hisoblanadi.

Ta'lim tizimida sun'iy intellekt texnologiyalaridan foydalanish o'qituvchi va talaba faoliyatini yengillashtiradi. Avvalo, sun'iy intellekt asosidagi tizimlar yordamida o'quv materiallarini tezkor tahlil qilish, bilimlarni avtomatik baholash hamda o'quvchilarning o'zlashtirish

¹⁰ O'zbekiston Respublikasi "Ta'lim to'g'risida"gi Qonuni 2020 yil 23 sentabr, O'RQ-637-son. - <https://lex.uz/docs/5013007>

¹¹ O'zbekiston Respublikasining "Ta'lim to'g'risida"gi Qonuni // Qonun hujjatlari ma'lumotlari milliy bazasi, 24.09.2020 y., 03/20/637/1313-son

¹² O'zbekiston Respublikasi Prezidentining 2025 yil 22 oktabrdagi "Sun'iy intellekt texnologiyalarini yanada rivojlantirishga oid qo'shimcha chora-tadbirlar to'g'risida" PF-189-son farmoni.<https://lex.uz/docs/-7789403#-7792137>

darajasini aniqlash mumkin. Masalan, elektron test tizimlari orqali talabalar bilimni baholash jarayoni avtomatlashtiriladi. Bu esa inson omili bilan bog'liq xatolarni kamaytiradi va natijalarning aniqligini oshiradi. Bundan tashqari, sun'iy intellekt o'quvchilarning qiziqishlari va qobiliyatlarini tahlil qilib, ularga mos ta'lim dasturlarini tavsiya qiladi[4].

Shuningdek, virtual yordamchilar va chatbot texnologiyalari talabalar savollariga tezkor javob berishda muhim rol o'ynaydi. Masalan, elektron ta'lim platformalarida sun'iy intellekt yordamida ishlovchi tizimlar 24 soat davomida foydalanuvchilarga xizmat ko'rsatishi mumkin.

Sun'iy intellekt texnologiyalarining asosiy afzalliklaridan biri — individual ta'limni rivojlantirish imkoniyatidir. Har bir talabaning bilim darajasi, qobiliyati va o'zlashtirish sur'ati turlicha bo'ladi. Sun'iy intellekt ana shu xususiyatlarni hisobga olib, o'quvchiga mos ta'lim yo'nalishini shakllantiradi. Masalan, ayrim o'quvchilar mavzuni tez o'zlashtirsa, boshqalari qo'shimcha tushuntirishga ehtiyoj sezadi. Sun'iy intellekt tizimi o'quvchi faoliyatini monitoring qilib, unga individual topshiriqlar va tavsiyalar beradi. Bu esa ta'lim samaradorligini oshirishga xizmat qiladi.

So'nggi yillarda masofaviy ta'limning rivojlanishi sun'iy intellekt texnologiyalariga bo'lgan ehtiyojni yanada oshirdi. Onlayn platformalar orqali darslarni tashkil etish, videodarslar yaratish, virtual laboratoriyalar tashkil qilish kabi imkoniyatlar kengaymoqda. Sun'iy intellekt yordamida masofaviy ta'lim jarayonida talabalar faolligi nazorat qilinadi, o'zlashtirish darajasi aniqlanadi va statistik ma'lumotlar tahlil qilinadi. Shu bilan birga, avtomatlashtirilgan tizimlar yordamida o'quv materiallarini tavsiya qilish va o'quv rejasini shakllantirish mumkin.

Big Data texnologiyalari katta hajmdagi ma'lumotlarni yig'ish, saqlash va qayta ishlash imkonini beradi. Ta'lim tizimida Big Data va sun'iy intellekt texnologiyalarining integratsiyasi orqali o'quvchilar faoliyatini chuqur tahlil qilish mumkin. Masalan, talabalarning fanlarni o'zlashtirish darajasi, davomati, mustaqil ishlari va test natijalari asosida umumiy tahlil olib boriladi. Ushbu ma'lumotlar asosida ta'lim sifatini oshirishga qaratilgan qarorlar qabul qilinadi.

Ta'lim tizimida sun'iy intellekt texnologiyalarining quyidagi afzalliklari mavjud:

- ta'lim sifatini oshiradi;
- individual yondashuvni ta'minlaydi;
- o'qituvchining vaqtini tejaydi;
- bilimlarni tezkor baholaydi;
- masofaviy ta'lim imkoniyatlarini kengaytiradi;
- raqamli ta'lim muhitini rivojlantiradi.

Biroq, sun'iy intellekt texnologiyalaridan foydalanishda ayrim muammolar ham mavjud. Jumladan, texnik infratuzilmaning yetarli emasligi, internet tezligining pastligi hamda ayrim pedagoglarning raqamli ko'nikmalari yetishmasligi ushbu texnologiyalarni keng joriy etishga to'sqinlik qilishi mumkin.

Demak, sun'iy intellekt texnologiyalari zamonaviy ta'lim tizimining ajralmas qismiga aylanmoqda. Ushbu texnologiyalar yordamida ta'lim sifatini oshirish, individual ta'limni rivojlantirish va o'quv jarayonini samarali tashkil etish mumkin. Kelajakda sun'iy intellekt asosidagi platformalardan foydalanish yanada kengayib, ta'lim tizimini yangi bosqichga olib chiqishi kutilmoqda. Shu sababli, ta'lim muassasalarida raqamli texnologiyalarni joriy etish va pedagoglarning axborot texnologiyalari bo'yicha bilimlarini oshirish muhim ahamiyatga ega.

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TA'LIM JARAYONIDA SUN'IY INTELEKTDAN SAMARALI FOYDALANISH

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Annotatsiya. Tezis raqamli didaktika sharoitida sun'iy intellektdan foydalanishning til, nutq va matn bilan ishlashga oid jihatlarini ham qamrab oladi. Maqsad o'quv matnlarini avtomatik tahlil qilish, yozma ishlar sifatini oshirish va individual o'quv traektoriyasini shakllantirish mexanizmlarini aniqlashtirishdir. Metodologiya sifatida tizimli yondashuv, holat tahlili va qiyosiy sinov natijalari umumlashtirildi. Yangilik sifatida o'qituvchi nazorati ostidagi gibrid baholash sxemasi asoslanadi.

Ta'lim jarayonida sun'iy intellektdan samarali foydalanish masalasi, avvalo, sun'iy intellektni o'qitish, o'rganish va baholashni qo'llab-quvvatlaydigan algoritmik va ma'lumotga tayanuvchi tizimlar majmui sifatida ta'riflashni talab qiladi. Bu ta'rif mexanizm jihatidan mashinaviy o'rganish, tabiiy tilni qayta ishlash va tavsiya tizimlari orqali o'quvchi faoliyati haqidagi signallarni yig'ish, ularni tahlil qilish va pedagogik qarorlarga aylantirish zanjiriga tayanadi. Masalan, yozma ishda grammatik xatolar, mantiqiy bog'lanishlar va uslubiy ko'rsatkichlar avtomatik ajratilib, o'quvchiga aniq teskari aloqa berilishi mumkin. Raqamli ta'lim platformalarida bunday yondashuvlar qo'llanganda, ayrim tadqiqotlarda o'quvchining qisqa muddatli natijalari 10–20 foiz atrofida yaxshilanishi, o'qituvchining tekshiruvga sarflaydigan vaqti esa 25–40 foizgacha qisqarishi qayd etiladi¹³. Ilmiy izoh sifatida bu natijalar “ma'lumot–qaror–ta'sir” siklining tezlashuvi bilan tushuntiriladi, ya'ni teskari aloqa vaqtida berilganda kognitiv mustahkamlash kuchayadi va xatoni tuzatish ehtimoli ortadi.

Sun'iy intellektning ta'limdagi samaradorligi didaktik maqsadlar bilan algoritmik imkoniyatlar o'rtasidagi moslikka bog'liq bo'lib, bu holat “didaktik moslik koeffitsienti” sifatida ta'riflanishi mumkin. Ushbu koeffitsientning mexanizmi shundan iboratki, model tavsiya qilayotgan kontent yoki baho mezonlari o'quv dasturi kompetensiyalari, o'quvchi darajasi va fan metodikasidagi ketma-ketlik talablariga qanchalik mos kelsa, pedagogik natija shunchalik barqaror bo'ladi. Masalan, adabiyotshunoslik va tilshunoslikka oid topshiriqlarda sun'iy intellekt bir vaqtning o'zida leksik boylik va dalillash madaniyatini tekshiradigan rubrika taklif qilsa, o'qituvchi uni o'quv maqsadlariga moslab qayta sozlaydi. Amaliy ko'rsatkich sifatida rubrika mezonlari 6–8 banddan oshib ketganda, o'quvchida kognitiv yuklama ortishi va vazifani bajarish sifati pasayishi ehtimoli kuzatiladi, shu sababli mezonlar sonini optimallashtirish talab etiladi¹⁴. Ilmiy izoh nuqtayi nazaridan, bu hodisa ishchi xotira cheklovlari va maqsadga yo'naltirilgan diqqat resurslarining taqsimlanishi bilan izohlanadi, ya'ni sun'iy intellekt tavsiyasi pedagogik psixologiya qonuniyatlariga mos kelishi zarur.

Adaptiv ta'lim sun'iy intellektning ta'limiy qo'llanishidagi markaziy yo'nalishlardan biri bo'lib, u o'quvchining individual ehtiyoji va sur'atiga mos kontentni avtomatik tanlash jarayoni sifatida ta'riflanadi. Mexanizm darajasida adaptiv tizimlar diagnostik testlar, faoliyat jurnallari va xatolar xaritasidan foydalangan holda bilim holatini ehtimollik modeli orqali baholaydi hamda keyingi topshiriq murakkabligini moslashtiradi. Masalan, til o'rganishda o'quvchi fe'l zamonlarini muntazam adashtirsa, tizim aynan shu mavzuga oid mikro-topshiriqlarni ko'paytirib, izohli misollarni taklif etadi. Ayrim platformalarda adaptiv marshrut qo'llanganda topshiriqlarni yakunlash darajasi 15–30 foizga oshgani va tashlab ketish holatlari 10–18 foizga kamaygani haqidagi natijalar uchraydi¹⁵. Ilmiy izoh sifatida bu samaradorlik “yaqin rivojlanish zonasi”ga mos murakkablikni ushlab turish bilan bog'lanadi, chunki juda oson vazifa motivatsiyani pasaytiradi, juda qiyini esa frustratsiyani kuchaytiradi.

¹³Holmes W., Bialik M., Fadel C. Artificial Intelligence in Education: Promises and Implications for Teaching and Learning. Boston: Center for Curriculum Redesign, 2019. 242 p.

¹⁴Воробьева Е. В. Цифровая дидактика: теория и практика проектирования обучения. Москва: Юрайт, 2021. 286 с.

¹⁵Russell S., Norvig P. Artificial Intelligence: A Modern Approach. Boston: Pearson, 2021. 1136 p.

Ta'limda sun'iy intellektdan foydalanishning muhim yo'nalishi avtomatlashtirilgan baholash bo'lib, u o'quv natijalarini standart mezonlar asosida tez va izchil o'lchashga qaratilgan tizim sifatida ta'riflanadi. Uning mexanizmi, odatda, klassifikatsiya va reytinglash modellari, matn xususiyatlari ekstraksiyasi hamda kalibrlash jarayonlari orqali ishlaydi, bunda o'qituvchi namunaviy javoblar to'plamini beradi va model shunga mos o'lchovlarni o'rganadi. Masalan, insho baholashda tizim mavzuga moslik, argumentlar tuzilishi, bog'lovchi vositalar va imlo xatolarini alohida indikatorlar sifatida qayd etib, yakuniy ballni taklif qiladi. Amaliy raqam sifatida, o'qituvchi-model kelishuvi 0,70–0,85 oralig'iga chiqqanda baholashdan foydalanish maqsadga muvofiq bo'lishi, 0,60 dan past bo'lsa rubrika va trening ma'lumotlarini qayta ko'rib chiqish zarurligi ko'rsatiladi¹⁶. Ilmiy izohga ko'ra, bunday kelishuv baholash ishonchliligining statistik ko'rsatkichi bo'lib, metodik jihatdan rubrika aniqligi va ma'lumotlar muvozanati ta'minlanmasa, model tarafkashligi kuchayadi.

Sun'iy intellektning til, nutq va matn bilan ishlashdagi imkoniyatlari tabiiy tilni qayta ishlash (NLP) yo'nalishi bilan bog'liq bo'lib, u matndan ma'no, tuzilma va uslubiy signallarni avtomatik ajratish texnologiyalari majmui sifatida ta'riflanadi. Mexanizm sifatida tokenizatsiya, lemmatizatsiya, semantik vektorlar va transformator arxitekturasini kabi yondashuvlar qo'llanadi, bu esa matnni mazmunij jihatdan solishtirish va xulosalashni tezlashtiradi. Masalan, o'quvchi referat yozganda tizim manbalar bilan semantik yaqinlikni tekshiradi, iqtiboslarni aniqlaydi va qayta bayon qilish darajasini ko'rsatadi. Akademik yozuv ko'nikmalarini rivojlantirishda bunday vositalar qo'llanganda plagiat riskini kamaytirish bilan birga, tahrir sifati oshishi kuzatiladi, ayrim taqqoslov tadqiqotlarda qayta topshirishlar soni 1,3 baravar kamaygani haqida ma'lumot beriladi¹⁷. Ilmiy izoh shundan iboratki, NLP vositalari matnning yuzaki o'xshashligidan tashqari, argumentatsiya va mantiqiy bog'lanishlarni ko'rsatib bera olganda, o'quvchi "matn madaniyati"ni chuqurroq anglaydi.

Sun'iy intellektning ta'limga joriy etishda ma'lumotlar sifati asosiy shart bo'lib, u modelni o'qitish va qaror chiqarish uchun ishlatiladigan ma'lumotlarning to'liqligi, dolzarbligi va xolisligi sifatida ta'riflanadi. Mexanizm jihatidan sifatsiz ma'lumot shovqin va noto'g'ri belgilashlar orqali model parametrlarini buzadi, natijada tavsiyalar pedagogik maqsadlarga zid bo'lib qolishi mumkin. Masalan, baholash ma'lumotlarida ayrim guruhlarining yozma ishlari kamroq bo'lsa, model ularning uslubiy xususiyatlarini "xato" deb belgilashga moyillashadi va baho adolatsizlashadi. Raqamli ko'rsatkich sifatida, trening to'plamida sinflar muvozanati 60/40 dan 80/20 ga og'sa, klassifikatsiya xatosi 5–12 foizga oshishi kuzatilishi mumkin, shu bois qayta namunalash va og'irlik koeffitsientlari tavsiya etiladi¹⁸. Ilmiy izohga ko'ra, bu muammo statistik tarafkashlik va generalizatsiya xatolari bilan izohlanadi, ya'ni pedagogik adolatni ta'minlash uchun ma'lumotlar auditi zarur.

Etik va xavfsizlik masalalari sun'iy intellektdan foydalanishda alohida o'rin tutadi, chunki u shaxsiy ma'lumotlar, intellektual mulk va akademik halollik bilan bog'liq xavflarni boshqarish tizimi sifatida ta'riflanadi. Mexanizm darajasida bu boshqaruv rozilik (consent), minimallashtirish (faqat zarur ma'lumotni yig'ish), shifrlash, kirish nazorati va audit jurnallari orqali amalga oshiriladi, shuningdek, generativ modellarda zararli kontent filtratsiyasi ham muhim hisoblanadi. Masalan, onlayn imtihonlarda proktoring yechimlari yuz tasviri, klaviatura dinamikasi yoki ekran faoliyatini qayd etishi mumkin, biroq bu jarayon aniq reglament va saqlash muddatlari bilan cheklanishi kerak. Amaliy jihatdan ma'lumotlar sizib chiqishi holatlarining ta'lim muassasalari uchun obro' va moliyaviy yo'qotishlari sezilarli bo'lib, ayrim xalqaro hisobotlarda kiberhodisalar oqibatidagi tiklash xarajatlari millionlab dollarga yetishi qayd etiladi, shu sababli risklarni oldindan baholash modeli zarur. Ilmiy izoh shundan iboratki, etik me'yorlar texnik chora-tadbirlar bilan birga, institutsional siyosat va o'qituvchi kompetensiyasi bilan mustahkamlangandagina barqaror natija beradi.

Sun'iy intellektdan samarali foydalanish uchun gibril pedagogik model zarur bo'lib, u "inson nazorati ostidagi avtomatlashtirish" tamoyiliga tayangan ta'limni tashkil etish shakli sifatida

¹⁶Salakhova N. R., Karimov A. M. Raqamli pedagogika va ta'lim analitikasi asoslari. Toshkent: O'qituvchi, 2022. 192 b.

¹⁷Jurafsky D., Martin J. H. Speech and Language Processing. Upper Saddle River: Prentice Hall, 2020. 1024 p.

¹⁸Witteveen D., Andrews J. Data Security and Privacy in Educational Technologies. London: Routledge, 2022. 248p.

ta'riflanadi. Mexanizm shundan iboratki, model taklif qiladi, o'qituvchi tekshiradi, o'quvchi qayta ishlaydi va natija yana tizim orqali monitoring qilinadi, ya'ni yopiq konturli sifat nazorati shakllanadi. Masalan, generativ model dars rejasi loyahasini tuzadi, o'qituvchi uni o'quv dasturiga moslaydi, so'ng o'quvchi refleksiya yozadi va tizim refleksiyadagi mavhumlik darajasini ko'rsatib, aniqlashtirish savollarini beradi. Bunday yondashuvda o'qituvchining vaqt tejallishi 20–35 foiz bo'lishi mumkin, biroq nazorat bosqichlari olib tashlansa xatolar va metodik nomuvofiqliklar ko'payishi ehtimoli ortadi. Ilmiy izoh sifatida gibrid model “avtomatlashtirishning chegaralari” konsepsiyasiga mos keladi, ya'ni mas'uliyat va interpretatsiya insonda qolsa, tizimning foydasi xavflardan ustun bo'ladi.

Ta'lim mazmunini loyihalashda sun'iy intellektdan foydalanish didaktik dizaynni qayta talqin qiladi, chunki u kontentni yaratish, moslashtirish va tekshirish jarayonlarini optimallashtiruvchi metodik vosita sifatida ta'riflanadi. Mexanizm darajasida kontent generatori o'quv maqsadlari, kompetensiya indikatorlari va baholash mezonlarini kirish ma'lumoti sifatida qabul qiladi, so'ng variantlar yaratadi va o'qituvchi tomonidan tahrirlanadi. Masalan, bir mavzu uchun turli murakkablikdagi test savollari, matnli topshiriqlar va keyslar yaratiladi, keyin ular Bloom taksonomiyasidagi darajalar bo'yicha saralanadi. Raqamli ko'rsatkich sifatida, bitta mavzu bo'yicha 30–50 ta savolni qo'lda tayyorlashga ketadigan vaqt bilan taqqoslaganda, sun'iy intellekt yordamida dastlabki bankni yaratish 3–5 baravar tezlashishi mumkin, lekin validatsiya bosqichi majburiy bo'lib qoladi. Ilmiy izoh shundan iboratki, kontent ishlab chiqish tezlashgani sari sifatni ushlab turish uchun ekspert tekshiruv, pilot sinov va statistik tahlilning roli ortadi, aks holda “tezlik–sifat” nomutanosibliyi yuzaga keladi.

Xulosa qilib aytganda, ta'lim jarayonida sun'iy intellektdan samarali foydalanish sun'iy intellektni didaktik maqsadga bo'ysundirish, ma'lumotlar sifatini ta'minlash, gibrid nazorat mexanizmini joriy etish va etik-xavfsizlik indikatorlarini institutsional darajada mustahkamlash bilan bog'liq. Tezida asoslangan yondashuv sun'iy intellektni o'qituvchi o'rnini bosuvchi emas, balki o'qitish, baholash va teskari aloqani aniqlashtiruvchi ilmiy vosita sifatida ko'radi. Taklif etilgan “didaktik moslik koeffitsienti” va “xavf-muvozanat profili” tushunchalari texnik imkoniyatlarni metodik talablar bilan muvofiqlashtirishga xizmat qiladi. Shuningdek, adaptiv ta'lim va NLP vositalari o'quvchining matn bilan ishlash kompetensiyasini oshirishga yordam beradi, biroq ularni joriy etishda rubrika aniqligi, audit va shaffoflik ustuvor bo'lishi lozim. Natijada, sun'iy intellekt pedagogik jarayonning sifatini oshirishi uchun texnologiya, metodika va boshqaruv bir butun tizim sifatida uyg'unlashtirilishi zarur.

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APPLICATION OF BLOCKCHAIN AND BIG DATA IN EDUCATION

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Abstract. The integration of blockchain technology and big data analytics into education has become one of the most significant trends in the digital transformation of modern society. Educational institutions increasingly face challenges related to data security, transparency, academic credential verification, personalized learning, and effective management of educational resources. Blockchain technology provides decentralized, transparent, and tamper-resistant systems for storing and managing educational records, while big data analytics enables the processing of massive educational datasets for predictive analysis and adaptive learning. This article investigates the application of blockchain and big data in education, analyzes current scientific literature, examines research methodologies, and evaluates the effectiveness of these technologies in educational environments. The study demonstrates that blockchain significantly improves the reliability and security of academic documentation, whereas big data contributes to data-driven decision-making and individualized learning approaches. The article also discusses implementation barriers, including technical infrastructure limitations, financial costs, legal concerns, and ethical issues associated with educational data processing. Based on the findings, practical recommendations for educational institutions and policymakers are proposed.

Keywords: blockchain, big data, digital education, educational technology, smart learning, academic credentials, learning analytics, cybersecurity, personalized education, digital transformation.

Introduction. The rapid development of digital technologies has transformed nearly every sector of human activity, including education. Educational systems worldwide are increasingly adopting innovative technologies to improve teaching quality, enhance learning outcomes, and optimize administrative management. The emergence of online learning platforms, cloud computing, artificial intelligence, and data-driven educational systems has created new opportunities for the modernization of education.

However, despite technological progress, traditional educational systems continue to face serious challenges. These include difficulties in verifying academic credentials, lack of transparency in educational management, limited personalization of instruction, inefficiency in data processing, cybersecurity threats, and inadequate protection of students' personal information. In many countries, educational institutions still rely on centralized databases that are vulnerable to hacking, manipulation, and data loss. Blockchain technology and big data analytics have emerged as innovative solutions capable of addressing these problems. Blockchain is a decentralized distributed ledger technology that records transactions securely and transparently. Its main characteristics include immutability, decentralization, transparency, and cryptographic security. Initially developed for cryptocurrency systems, blockchain has expanded into various fields such as healthcare, finance, logistics, and education.

Literature Review. The application of blockchain and big data in education has attracted increasing attention from researchers worldwide. Numerous studies have explored the theoretical foundations, practical applications, and implications of these technologies for educational systems.

Tapscott and Tapscott [1] argue that blockchain technology represents a revolutionary innovation capable of transforming multiple industries, including education. According to their research, blockchain enables the creation of decentralized systems that increase transparency and eliminate the need for intermediaries. In education, blockchain can simplify academic credential verification and reduce administrative bureaucracy.

Grech and Camilleri [2] investigated blockchain applications in higher education and emphasized that blockchain-based credentials can reduce diploma fraud and improve international recognition of qualifications. Their study also highlighted the potential of blockchain for lifelong learning records and decentralized educational identities.

Sharples and Domingue [3] proposed the concept of blockchain-supported lifelong learning systems. They suggested that students could own and control their educational achievements through secure digital wallets, enabling easier mobility across institutions and countries. Research conducted by Chen, Mao, and Liu [4] demonstrated that big data analytics has become an essential component of modern educational systems. Their findings indicate that educational institutions can

improve learning outcomes by analyzing student behavior, engagement patterns, and academic performance. Siemens and Long [5] focused on learning analytics and emphasized the importance of educational data mining for improving instructional strategies. According to the authors, predictive analytics can help identify students at risk of academic failure and enable early intervention.

Williamson [6] analyzed the social and ethical dimensions of big data in education. The study pointed out that while big data offers significant advantages, it also raises concerns regarding surveillance, student privacy, and algorithmic bias. In Central Asian academic research, Karimov [7] emphasized that digital technologies are becoming strategic priorities for educational modernization. According to the author, the implementation of blockchain and big data can improve educational accessibility and administrative management in developing countries. The literature review demonstrates that blockchain and big data technologies have significant potential in education. However, researchers also identify major challenges related to infrastructure, legislation, ethical standards, and technical competencies.

Research Methodology. This study is based on both qualitative and quantitative research approaches. The research methodology combines theoretical analysis, comparative analysis, and evaluation of case studies related to blockchain and big data implementation in education.

Research Methods. The following methods were used in this research:

1. **Literature Analysis.** Scientific articles, conference proceedings, books, and reports related to blockchain and big data in education were analyzed. The literature review focused on identifying current trends, advantages, limitations, and implementation strategies.

2. **Comparative Analysis.** Comparative analysis was conducted to evaluate differences between traditional educational systems and technology-enhanced systems using blockchain and big data.

3. **Case Study Method.** Several international universities and educational platforms implementing blockchain and big data technologies were examined. The analysis focused on their operational effectiveness and implementation outcomes.

4. **Statistical Analysis.** Secondary statistical data obtained from international educational reports and scientific publications were analyzed to identify technological adoption trends.

Analysis and Discussion of Results.

Blockchain Applications in Education. The study revealed several important applications of blockchain technology in education.

Academic Credential Verification. One of the major problems in education is diploma fraud. Traditional verification systems are often slow and inefficient. Blockchain technology allows educational institutions to issue digital certificates that can be instantly verified.

Table 1. Blockchain-based verification systems

Indicator	Traditional System	Blockchain System
Verification Time	Several days	Several seconds
Risk of Fraud	High	Very low
Data Security	Moderate	High
Transparency	Limited	High

The results indicate that blockchain-based verification systems significantly improve reliability and efficiency. **Smart Contracts in Education.** Smart contracts automate educational processes such as tuition payments, scholarship distribution, and course completion certification. These systems reduce administrative workload and minimize human errors. **Big Data Applications in Education.** Big data analytics plays an important role in improving educational quality.

Personalized Learning. Educational platforms collect data about students' learning styles, progress, and engagement. Big data analytics allows systems to adapt learning materials according to individual needs.

Table 2. Big Data functions and benefits in education

Big Data Function	Educational Benefit
Predictive	Identification of at-risk

Analytics	students
Learning Analytics	Personalized instruction
Behavioral Tracking	Increased engagement
Curriculum Analysis	Improved course quality

Predictive Student Performance Analysis. Educational institutions can predict student success rates based on historical performance data. This enables early academic interventions. Improvement of Institutional Management. Big data helps administrators optimize scheduling, resource allocation, and educational planning.

Conclusions and Recommendations. The research confirms that blockchain and big data technologies have significant potential to transform modern education. Blockchain improves security, transparency, and trust in educational data management, while big data analytics enhances personalized learning and institutional efficiency.

The study supports the proposed hypotheses and demonstrates that the integration of these technologies contributes to the development of intelligent educational ecosystems.

Future research may focus on the integration of artificial intelligence, blockchain, and big data within smart education systems.

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ARTIFICIAL INTELLIGENCE IN EDUCATION: TRANSFORMING TEACHING, LEARNING, AND ASSESSMENT IN THE DIGITAL AGE

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Abstract. Artificial intelligence (AI) has become one of the most transformative technologies of the twenty-first century, significantly influencing various sectors, including education. The integration of AI into educational systems has created new opportunities for improving teaching methodologies, personalizing learning experiences, automating assessment processes, and

enhancing institutional management. AI technologies such as machine learning, natural language processing, intelligent tutoring systems, and predictive analytics enable educational institutions to adapt learning environments to the needs of individual students. This article examines the role of artificial intelligence in education, analyzes its applications in teaching, learning, and assessment, and evaluates the benefits and challenges associated with AI implementation in modern educational systems. The study is based on literature analysis, comparative research, and examination of contemporary educational technologies. The findings demonstrate that AI improves educational efficiency, increases student engagement, and supports data-driven decision-making. However, ethical concerns, data privacy issues, technological inequality, and the need for teacher training remain significant challenges. The article concludes with recommendations for effective integration of AI technologies into education and identifies future directions for research.

Keywords: artificial intelligence, education technology, digital learning, intelligent tutoring systems, adaptive learning, educational assessment, machine learning, smart education, learning analytics, digital transformation.

Introduction. The rapid development of digital technologies has fundamentally transformed the educational landscape. Educational institutions worldwide are increasingly adopting technological innovations to improve the quality of teaching, optimize administrative processes, and enhance students' learning experiences. Among these innovations, artificial intelligence (AI) has emerged as one of the most influential technologies reshaping modern education.

Artificial intelligence refers to computer systems capable of performing tasks that typically require human intelligence, such as problem-solving, decision-making, speech recognition, language understanding, and pattern analysis. AI technologies include machine learning, deep learning, natural language processing, computer vision, robotics, and predictive analytics. These technologies are increasingly integrated into educational environments to create intelligent and adaptive learning systems. The relevance of AI in education has grown significantly due to several global factors. First, the expansion of online and blended learning environments has increased the need for automated educational tools capable of supporting large numbers of students. Second, modern educational systems require personalized learning approaches that address the diverse needs, abilities, and learning styles of students. Third, educational institutions are under pressure to improve academic outcomes while reducing operational costs and increasing efficiency.

Literature Review. The role of artificial intelligence in education has been widely discussed by researchers from different countries and academic disciplines. Existing studies demonstrate that AI technologies have the potential to transform educational systems by improving instructional quality, increasing accessibility, and supporting personalized learning.

Russell and Norvig [1] define artificial intelligence as the simulation of human intelligence processes by machines and emphasize its growing importance in modern society. Their work provides theoretical foundations for understanding AI technologies and their applications in education.

Holmes, Bialik, and Fadel [2] explored the relationship between AI and education and argued that intelligent technologies can significantly improve teaching and learning processes. According to the authors, AI enables adaptive educational systems capable of responding to individual student needs.

Luckin et al. [3] investigated the use of AI-powered tutoring systems and concluded that intelligent tutoring technologies improve student engagement and academic performance. Their research demonstrated that AI systems can provide immediate feedback and personalized instructional support. Williamson and Eynon [6] examined the ethical implications of AI in education. The authors emphasized concerns related to algorithmic bias, surveillance, privacy, and digital inequality. They argued that educational institutions must ensure responsible and transparent use of AI technologies. Several scholars from developing countries have also explored digital transformation in education. Karimov [9] emphasized that AI technologies can improve educational accessibility and quality in regions with limited educational resources. The literature review demonstrates that artificial intelligence is becoming a key driver of educational innovation.

However, researchers also underline challenges related to ethics, infrastructure, digital competencies, and regulatory frameworks.

Research Methodology. This study employs both qualitative and quantitative research methods to investigate the role of artificial intelligence in education.

Research Methods. The following methods were applied:

1. Literature Analysis. Scientific articles, books, conference proceedings, and reports related to AI in education were analyzed to identify theoretical concepts, practical applications, and implementation trends.

2. Comparative Analysis. Comparative analysis was conducted to evaluate differences between traditional educational systems and AI-supported educational environments.

3. Case Study Analysis. Case studies from universities and educational platforms implementing AI technologies were examined to assess their effectiveness.

4. Statistical Analysis. Secondary statistical data from educational reports and academic studies were analyzed to identify global AI adoption trends in education.

Analysis and Discussion of Results.

AI Applications in Teaching. Artificial intelligence significantly transforms teaching methodologies by supporting automation, personalization, and intelligent instructional design.

Intelligent Tutoring Systems. AI-powered tutoring systems simulate personalized teacher-student interactions. These systems analyze students' responses and adapt instructional materials according to individual learning needs.

Table 1. Intelligent Tutoring Systems.

AI Teaching Tool	Educational Function
Intelligent Tutoring Systems	Personalized instruction
Virtual Assistants	Student support
Chatbots	Automated communication
Recommendation Systems	Adaptive content delivery

The analysis indicates that AI tutoring systems improve student engagement and learning efficiency.

AI Applications in Learning. Personalized Learning.

One of the most important advantages of AI is its ability to support personalized learning. AI systems analyze students' learning styles, progress, strengths, and weaknesses to create adaptive educational pathways.

Table2. AI Applications in Learning.

Personalized Learning Feature	Educational Benefit
Adaptive Learning Systems	Individualized instruction
Learning Analytics	Improved performance monitoring
Predictive Algorithms	Early intervention
Recommendation Engines	Customized educational resources

The findings show that personalized learning increases student motivation and academic achievement.

Conclusions and Recommendations. The research confirms that artificial intelligence plays a transformative role in modern education. AI technologies significantly improve teaching, learning, and assessment processes by supporting personalization, automation, and data-driven educational management. The study validates the proposed hypotheses and demonstrates that AI contributes to the development of smart educational ecosystems capable of addressing contemporary educational challenges.

The following conclusions were reached:

AI technologies improve educational quality and operational efficiency.

Personalized learning systems increase student engagement and academic achievement.

Automated assessment tools enhance objectivity and speed of evaluation.

Ethical, legal, and social challenges remain significant barriers to AI implementation.

Based on the findings, the following recommendations are proposed:

Educational institutions should invest in AI infrastructure and digital resources;

Governments should develop ethical and legal regulations for AI in education;

Teacher training programs should include AI literacy and digital pedagogy;

Educational institutions should prioritize data privacy and cybersecurity;

International cooperation should be encouraged to share best practices in AI-supported education.

Future research should focus on the integration of artificial intelligence with blockchain, virtual reality, and big data technologies in smart education systems.

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FILOLOGIK TA'LIM YO'NALISHLARIDA SUN'IY INTELLEKT VA BULUTLI SERVISLAR ASOSIDA "AXBOROT TEXNOLOGIYALARI" FANINI O'QITISH TAJRIBASI

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Annotatsiya. Mazkur tezisda filologik ta'lim yo'nalishlari talabalariga "Axborot texnologiyalari" fanini o'qitishda HEMIS tizimi, bulutli servislar va sun'iy intellekt texnologiyalaridan foydalanish tajribasi tahlil qilingan. Xususan, mustaqil ta'limni tashkil etish, onlayn nazoratni amalga oshirish, amaliy topshiriqlarni bajarish hamda ChatGPT asosidagi konsultativ yordam mexanizmlarining pedagogik imkoniyatlari yoritilgan. Amaliy kuzatuvlar davomida HEMIS, Google xizmatlari, Canva va ChatGPT platformalarining integratsiyalashgan holda qo'llanilishi talabalar raqamli kompetensiyalarini rivojlantirish va mustaqil ta'lim faolligini oshirishga ijobiy ta'sir ko'rsatgani aniqlandi.

Kalit so'zlar: HEMIS, sun'iy intellekt, ChatGPT, bulutli servislar, raqamli kompetensiya, filologik ta'lim, mustaqil ta'lim.

Asosiy qism

Bugungi kunda oliy ta'lim tizimida raqamli transformatsiya jarayonlari jadallashib, pedagogik faoliyatning muhim tarkibiy qismiga aylanmoqda [1]. Ayniqsa, filologik ta'lim yo'nalishlarida tahsil olayotgan talabalar uchun raqamli kompetensiyalarni shakllantirish dolzarb

vazifalardan biri hisoblanadi. Zamonaviy mutaxassis nafaqat xorijiy tilni bilishi, balki raqamli platformalar, bulutli servislar va sun'iy intellekt vositalaridan samarali foydalana olishi ham talab etiladi [2].

Amaliy kuzatuvlar shuni ko'rsatadiki, filologik ta'lim yo'nalish talabalarida axborot texnologiyalariga oid nazariy bilimlar yetarli bo'lsa-da, ayrim hollarda amaliy raqamli ko'nikmalarni shakllantirish, mustaqil ishlashni tashkil etish hamda zamonaviy onlayn servislar bilan ishlashda qiyinchiliklar kuzatiladi. Mazkur muammoni bartaraf etish maqsadida "Axborot texnologiyalari" fanini o'qitishda HEMIS tizimi, Google xizmatlari, Canva platformasi hamda ChatGPT kabi sun'iy intellekt vositalarini integratsiyalashgan holda qo'llash metodikasi amaliyotga tatbiq qilindi.

Mashg'ulotlarni tashkil etishda HEMIS tizimi asosiy elektron boshqaruv platformasi sifatida qo'llandi: o'quv materiallari joylashtirildi, mustaqil topshiriqlar yuborildi, onlayn testlar o'tkazildi va talabalar faolligi monitoring qilindi [8]. Bu o'quv jarayonining tizimliliigi hamda nazorat samaradorligini oshirishga xizmat qildi. Zamonaviy raqamli ta'lim muhitida bilim almashinuvi va mustaqil o'rganish jarayonlari tarmoqli yondashuv asosida shakllanmoqda [5]. Shu sababli ta'limni boshqaruv tizimlari (LMS) platformalari, bulutli servislar va sun'iy intellekt vositalarini integratsiyalashgan holda qo'llash ta'lim samaradorligini oshirishning muhim omillaridan biri hisoblanadi. Amaliy mashg'ulotlarda ingliz va nemis tili yo'nalishidagi guruhlarda mustaqil ta'lim ishlari tashkil qilindi. Talabalarga SMART ta'lim, bulutli texnologiyalar, Google xizmatlari va MOODLE tizimi mavzularida topshiriqlar berildi. Dastlabki qiyinchiliklar bartaraf etilib, talabalar raqamli ko'nikmalarida ijobiy o'zgarish kuzatildi [6]. Talabalarga MS Word, Excel va PowerPoint bo'yicha bosqichma-bosqich amaliy topshiriqlar berildi: matn formatlash, jadval va diagrammalar yaratish, taqdimot tayyorlash [7].

Amaliy monitoring natijalariga ko'ra, talabalarining 60 foizga yaqini lokal MS Office, qolgan qismi Google Docs/Sheets/Slides dan foydalandi. Taqdimotlarda esa Canva platformasi eng faol vosita bo'ldi — uning mobil qurilmalarga moslashgan interfeysi talabalar prezentatsiyalarining vizual sifati va dizayn madaniyatini rivojlantirishga xizmat qildi [6].

So'nggi yillarda generativ sun'iy intellekt vositalarining ta'lim jarayonidagi imkoniyatlari kengayib bormoqda [3,4]. Amaliy kuzatuvlar davomida ChatGPT platformasidan tayyor javob manbai sifatida emas, balki individual konsultativ yordam vositasi sifatida foydalanildi.

Talabalar ChatGPT yordamida prezentatsiya matnlari tayyorlash, jadval va diagrammalar yaratish, amaliy topshiriqlar bo'yicha qo'shimcha tushuntirishlar olish hamda mustaqil ishlash jarayonida yuzaga kelgan texnik masalalar bo'yicha yo'naltiruvchi tavsiyalar oldi. Filologik ta'lim yo'nalish talabalarida texnik fanlarga qiziqish darajasi turlicha bo'lishi sababli sun'iy intellekt vositalari murakkab mavzularni sodda va tushunarli shaklda tushuntirishda samarali pedagogik vosita sifatida xizmat qildi.

Masalan, bulutli texnologiyalar mavzusida qiyinchilikka duch kelgan talabalarga ChatGPT orqali bosqichma-bosqich ko'rsatmalar berilishi raqamli kompetensiyalarni shakllantirish jarayoniga ijobiy ta'sir ko'rsatdi [3].

HEMIS orqali tashkil etilgan onlayn testlar talabalar bilimini tezkor baholash, monitoring va teskari aloqani kuchaytirish imkonini berdi. Oraliq nazorat natijalari mustaqil topshiriqlar bajarish faolligining oshganini ko'rsatdi [8].

Natijada talabalarining mustaqil ishlash faolligi, raqamli servislar bilan ishlash ko'nikmalari hamda zamonaviy IT vositalaridan foydalanish kompetensiyasi sezilarli darajada faollashgani kuzatildi. HEMIS tizimi, bulutli servislar va sun'iy intellekt texnologiyalarining integratsiyalashgan holda qo'llanilishi filologik ta'lim yo'nalishlari talabalarining zamonaviy raqamli muhitga moslashuvchanligini oshirishga xizmat qildi.

Biroq sun'iy intellekt texnologiyalaridan foydalanishda ayrim muammolar ham mavjud. Xususan, sun'iy intellekt tomonidan taqdim etilgan ma'lumotlarning har doim ham to'liq ishonchli bo'lmasligi, tayyor javoblarga ortiqcha tayanish va akademik halollik bilan bog'liq masalalar pedagogdan doimiy metodik nazoratni talab qiladi. Shu sababli sun'iy intellekt vositalaridan

foydalanishda tanqidiy fikrlash va axborotni tahlil qilish ko'nikmalarini shakllantirish muhim ahamiyat kasb etadi.

Xulosa. Amaliy kuzatuvlar natijalari HEMIS tizimi, bulutli servislar va sun'iy intellekt texnologiyalarini integratsiyalashgan holda qo'llash filologik ta'lim yo'nalishi talabalarining raqamli kompetensiyasini oshirish hamda mustaqil ta'lim faolligini kuchaytirish uchun samarali metodologik model ekanini tasdiqladi.

Canva platformasi vizual fikrlash va dizayn madaniyatini, ChatGPT esa texnik mavzularni o'zlashtirishni qo'llab-quvvatladi. Mazkur yondashuv boshqa fanlar o'qituvchilari tomonidan ham tatbiq etilishi mumkin bo'lgan samarali metodik model sifatida tavsiya etiladi.

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KOMPYUTER GRAFIKASIDA SUN'IY INTELLEKT: TASVIR YARATISH, ANIMATSIYA VA REAL VAQT RENDERLASHNING YANGI DAVRI

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Annotatsiya. Ushbu maqola kompyuter grafikasida sun'iy intellekt (SI) texnologiyalarining qo'llanilishini keng qamrovli tahlil qiladi. So'nggi yillarda generativ neyron tarmoqlar, ayniqsa, diffuziya modellari, generator-qarama-qarshi tarmoqlar (GAN) va transformator arxitekturalari kompyuter grafikasida inqilob qildi. Maqolada SI asosida matndan tasvir yaratish (masalan, DALL-E, Midjourney, Stable Diffusion), 2D va 3D modellashtirishda avtomatlashtirish, animatsiyada harakatni bashorat qilish, real vaqt renderlashda superrezolyutsiya va anti-aliasing, shuningdek, video o'yinlarda protsessual generatsiya kabi yo'nalishlar tahlil etiladi. Shuningdek, SI vositalarining an'anaviy kompyuter grafikasi pipeline'iga integratsiyasi, stilizatsiya va ekspressiv vizual effektlar yaratishdagi roli, hamda mualliflik huquqi va kreativlikka ta'siri kabi muammolar muhokama qilinadi. Xulosa qilib aytganda, sun'iy intellekt kompyuter grafikasini demokratlashtirmoqda, ammo yangi axloqiy va texnik masalalarni ham keltirib chiqarmoqda.

Kalit so'zlar: sun'iy intellekt, kompyuter grafikasi, generativ neyron tarmoqlar, matndan tasvir yaratish, diffuziya modellari, GAN, 3D modellashtirish, animatsiya, real vaqt renderlash, protsessual generatsiya.

Kompyuter grafikasi – so'nggi o'n yillikda eng tez rivojlanayotgan sohalardan biri. Realistik tasvirlarni yaratish, murakkab 3D modellarni qurish, tabiiy harakatlarni animatsiya qilish va real

vaqt rejimida renderlash – bularning barchasi doimiy ravishda yangi algoritmlarni talab qiladi. Aynan shu nuqtada sun'iy intellekt (SI) kompyuter grafikasiga yangi paradigmani olib kirdi.

An'anaviy kompyuter grafikasi asosan fizik asoslangan modellar (masalan, nurlarni kuzatish algoritmlari, fyuzion modellari) va qat'iy matematik formulalarga tayanadi. SI esa, aksincha, katta hajmdagi vizual ma'lumotlardan o'rganib, yangi, oldin ko'rilmagan tasvirlarni yaratish qobiliyatiga ega.

Ushbu maqolaning maqsadi – kompyuter grafikasida sun'iy intellektning asosiy qo'llanish yo'nalishlarini, texnologik asoslarini va kelajak istiqbollarini tizimli ravishda yoritish.

Asosiy texnologiyalar. Generator-qarama-qarshi tarmoqlar (GAN) - Ian Goodfellow va uning hamkasblari tomonidan 2014 yilda taklif qilingan GANlar ikki neyron tarmoq – generator va diskriminator – o'rtasidagi o'yin asosida ishlaydi. Generator yangi tasvirlar yaratishga harakat qiladi, diskriminator esa ularning haqiqiylikini aniqlashga. StyleGAN (NVIDIA, 2018-2020) oilasi ushbu sohada eng muvaffaqiyatli arxitekturalardan biri bo'lib, yuqori sifatli, sozlanishi mumkin bo'lgan portretlar va boshqa obyektlarni yaratadi.

Diffuziya modellari. 2021-2022 yillarda diffuziya modellari (DDPM, Denoising Diffusion Probabilistic Models) tasvir yaratishda GANlarni ortda qoldirdi. Ular tasodifiy shovqindan boshlab, bosqichma-bosqich shovqinni yo'qotish orqali tasvirni “ochadi”. Stable Diffusion, DALL-E 2 va Midjourney shu arxitekturaga asoslangan. Transformatorlar va VAE (Variational Autoencoders) - Transformator arxitekturasi, xususan, CLIP (Contrastive Language-Image Pre-training) matn va tasvirni birgalikda o'rganadi. Bu SI ga “qizil maydonda o'tirgan mushuk” kabi murakkab til buyruqlarini tasvirga aylantirish imkonini beradi.

Qo'llanish sohalari. Matndan tasvir yaratish (Text-to-Image) - eng mashhur va tez rivojlanayotgan yo'nalish. DALL-E 3, Midjourney v6, Stable Diffusion XL kabi modellar foydalanuvchining matnli tavsifi asosida fotorealistik yoki badiiy tasvirlar yaratadi.

Texnik jihatlar: CLIP matn kodlash, diffuziya jarayoni, samplar (DDIM, Euler, DPM++). Amaliy dasturlar: kontseptual san'at, reklama, UI/UX dizayn, o'yin resurslari, prototiplash.

Tasvirdan tasvir yaratish (Image-to-Image) - mavjud tasvirni o'zgartirish: rasmdan eskizni to'ldirish (inpainting), rang berish, obyektini olib tashlash, uslubni o'tkazish (style transfer).

Masalan: NVIDIA'ning GauGAN – foydalanuvchi oddiy rangli dog'lar chizadi, SI ularni real landshaftga aylantiradi.

3D modellashtirish va rekonstruksiya. SI fotosuratlardan 3D model yaratadi (NeRF – Neural Radiance Fields, Instant-NGP). NeRF texnologiyasi bir nechta 2D suratlardan to'liq 3D sahnani qayta qurish imkonini beradi. 2023-2024 yillarda Gaussian Splatting usuli paydo bo'ldi – bu real vaqt rejimida yuqori sifatli 3D rekonstruksiyaning amalga oshiradi.

Dasturlar: AR/VR, merosni raqamlashtirish, e-tijorat (mahsulot 3D vizualizatsiyasi).

Animatsiya va harakatni generatsiya qilish. SI asosida:

Suyaklarga avtomatik rigging (Auto-Rig Pro, Mixamo'ning AI versiyalari)

Harakatni bashorat qilish (motion prediction) – videodan keyingi kadrlarni yaratish

3D skeletdan real harakatni generatsiya qilish (MotionCLIP, MDM – Motion Diffusion Model)

Misol: Meta's Make-A-Video va Google's Imagen Video matnli tavsifdan qisqa videokliplar yaratadi.

Real vaqt renderlashda SI. Superrezolyutsiya (DLSS – Deep Learning Super Sampling): NVIDIA'ning DLSS texnologiyasi past piksellı tasvirni real vaqtda yuqori sifatli qilib oshiradi. SI ketma-ket kadrlardan foydalanib, yo'qolgan detallarni bashorat qiladi.

Anti-aliasing va denoising: SI yordamida kam sonli nurlar bilan ham shovqinsiz, silliq tasvir olinadi (OptiX Denoiser, NVIDIA).

Tekssturalarni avtomatik generatsiya: SI kichik namunaviy tekssturadan keng, takrorlanadigan materiallar yaratadi.

Protessual generatsiya (video o'yinlar va virtual dunyolar). SI o'yin dunyolari, xaritalar, binolar, o'simliklar va hatto butun ekotizimlarni avtomatik yaratadi. Masalan, Promethean AI – SI yordamida 3D sahnalarni so'z bilan tavsiflash orqali qurish.

Afzallik: rassom va dizaynerlarning yukini kamaytiradi, noyob va keng dunyolarni tez yaratish imkonini beradi.

An'anaviy kompyuter grafikasi pipeline'iga SI integratsiyasi. Zamonaviy grafik dasturlari (Blender, Adobe Photoshop, Autodesk Maya, Unreal Engine, Unity) SI vositalarini o'z ichiga olib bormoqda.

Dastur	SI funksiyasi
Adobe Photoshop	Generative Fill (obyektlarni olib tashlash/qo'shish)
Blender	Stable Diffusion qo'shimchalari (teksstura, material yaratish)
Unreal Engine 5	MetaHuman (SI bilan real odam modellari), DLSS
Unity	ArtEngine (materiallarni avtomatik optimizatsiya)
DaVinci Resolve	Magic Mask (SI asosida obyektни ajratish)

Afzalliklar va imkoniyatlar. Tezlik: Soatlab yoki kunlab davom etgan ishlar sekundlarda bajariladi.

Demokratizatsiya: Grafika sohasiga professional bo'lmagan foydalanuvchilar ham kirish imkoniyatiga ega bo'ladi.

Cheksiz kreativlik: SI oldin mavjud bo'lmagan uslublar, gibril tasvirlar yaratadi.

Qayta ishlash avtomatizatsiyasi: Fotolarni tozalash, rang tuzatish, fonni olib tashlash kabi "zerikarli" vazifalar avtomatlashadi.

Muammolar va cheklovlar. Mualliflik huquqi va kreativlik - SI modellari milliardlab internet tasvirlari ustida o'rgatilgan – ko'pincha rassomlarning ruxsatisiz. Bu huquqiy nizolarni keltirib chiqarmoqda. Stability AI, Midjourney va DeviantArt ga qarshi bir necha sud da'volari mavjud (2023-2024).

Savol: SI yaratgan tasvirga kim egalik qiladi? Foydalanuvchi? SI kompaniyasi? O'qitilgan rassomlar?

"Gallyutsinatsiya" va anatomik xatolar. SI ba'zan inson qo'lida 6 barmoq, g'ayritabiiy soya, noto'g'ri perspektiva yaratadi. Kichik detallar (matn, soat, ko'z qorachig'i) ko'pincha buziladi.

Nazorat qilish qiyinligi. An'anaviy 3D modellashtirishda har bir nuqta, har bir poli gon aniq belgilanadi. SI esa "qora quti" – nima uchun u tasvirning bir qismini qizil qilganini tushuntirish qiyin.

Energiya va hisoblash resurslari. Katta SI modellarini o'qitish minglab GPU soatlarini talab qiladi, bu esa atrof-muhitga salbiy ta'sir ko'rsatadi. Real vaqt generatsiyasi ham kuchli apparatni (masalan, RTX 4090) talab qiladi.

Kelajak istiqbollari. Video generatsiyasi: Hozircha qisqa (2-4 sekund) va sifatsiz, ammo Sora (OpenAI, 2024) va Kling (China) bir daqiqagacha real videolarni matndan yaratishni ko'rsatdi.

Interaktiv 3D sahnalar: SI bilan real vaqtda o'zgaradigan, gaplashish mumkin bo'lgan virtual dunyolar.

Multimodal modellar: Bitta SI matn, tasvir, audio va 3D obyektни birgalikda yaratadi.

Fizik asoslangan SI render: SI nafaqat ko'rinish, balki yorug'lik, material, og'irlik kabi fizik xususiyatlarni ham tushunadi.

Xulosa. Sun'iy intellekt kompyuter grafikasini tubdan o'zgartirmoqda. Endi rassom yoki dizayner bo'lish uchun yillar davomida texnik ko'nikmalarni o'rganish shart emas – to'g'ri prompt yozish va SI vositalarini boshqarish yetarli. Biroq, bu texnologik yutuq mualliflik huquqi, kreativ mehnat qadri va mehnat bozorining o'zgarishi kabi jiddiy axloqiy va ijtimoiy savollarni ham keltirib chiqarmoqda.

Kompyuter grafikasining kelajagi – inson va SI hamkorligida. SI takrorlanuvchi, zerikarli yoki haddan tashqari murakkab vazifalarni bajarsa, inson kontseptsiya, hissiyot, hikoya va ekspressiv ma'no ustida ishlaydi. Ushbu sinergiya kompyuter grafikasining yangi "oltin asri" bo'lishi mumkin.

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OLIY TA'LIMDA "SONLI USULLAR" FANINI O'QITISHDA SUN'IY INTELLEKT TEXNOLOGIYALARIDAN FOYDALANISH METODIKASI

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Annotatsiya: Maqolada oliy ta'limdagi "Sonli usullar" kursini o'qitishda sun'iy intellekt (SI) texnologiyalarini qo'llash imkoniyatlari tahlil qilingan. Adaptiv o'qitish tizimlari, katta til modellari va avtomatlashtirilgan maslahat tizimlari asosida dars jarayonini takomillashtiruvchi yondashuv taklif etilgan va uning amaliy sinovi natijalari keltirilgan.

Kalit so'zlar: sun'iy intellekt, sonli usullar, adaptiv o'qitish, LLM, GitHub Copilot, intelligent tutoring systems.

1. Kirish

Sonli usullar (hisoblash matematikasi) amaliy masalalarning modellari bo'lmish matematik masalalarni taqribiy yechish uchun taqribiy (sonli) usullar yaratish bilan shug'ullanadi.

Mazkur fan amaliy ahamiyati jihatidan juda keng qamrovli: mexanika, gidrodinamika, iqtisodiy modellashtirish va sun'iy intellektning o'zi ham ko'p hollarda sonli usullarga tayanadi. Shunga qaramay, an'anaviy o'qitish formatida ushbu fan talabalar uchun ayniqsa qiyin bo'lib qolishi kuzatiladi: algoritmning nazariy asosini tushunish bilan amaliy dasturlash ko'nikmalari orasidagi bo'shliq ko'pincha jiddiy to'siq yaratadi [1]. Talabalar ko'pincha formulani yodlab olsada, uni dasturiy muhitda qo'llashda qiynaladilar yoki aksincha — kodni ishlatganda, algoritmnining matematik mohiyatini tushunmaydilar.

Bugungi kunda sun'iy intellekt (SI) texnologiyalari aynan shu ikki tomonlama muammoni hal etishning istiqbolli vositasiga aylanib bormoqda. Xususan, katta til modellari (LLM), adaptiv o'qitish platformalari va intellektual maslahatchi tizimlar (ITS) talabaga ham nazariy tushuntirish, ham amaliy kod generatsiyasi bo'yicha bir vaqtning o'zida yordam bera oladi. Nafaqat xorijiy, balki O'zbekiston oliy ta'lim muassasalarida ham SI yordamchi vositalar sifatida jadal joriy etilmoqda: 2023–2024 o'quv yilidan boshlab bir qator universitetlarda raqamli ta'lim platformalari va AI-assistentlardan foydalanish rasman tashkil etildi[2]. Ushbu maqolada "Sonli usullar" fanini o'qitishda SI texnologiyalarini qo'llashning aniq metodikasi taklif etiladi va uning amaliy sinov natijalari tahlil qilinadi.

2. SI texnologiyalari va ularning ta'limdagi funksiyalari

Zamonaviy SI ekotizimida oliy ta'lim uchun uchta asosiy yo'nalish ajralib turadi.

Katta til modellari (LLM). ChatGPT, GPT-4, Claude va shunga o'xshash modellar talabani og'zaki savoliga javob berib, algoritmnining ishlash mantiqini tushuntiradi, Python yoki MATLAB kodini generatsiya qiladi, xatolarni diagnostika qiladi va muqobil yondashuvlarni taqqoslab ko'rsatadi. Masalan, "kesmani ikkiga bo'lish usuli nima uchun har doim yaqinlashadi?" degan savolga LLM faqat ta'rif bermasdan, oraliq teoremasi asosida mantiqiy izoh qurib beradi. Tadqiqotlar LLMlardan foydalanilgan guruhlarda STEM fanlar bo'yicha o'zlashtirish ko'rsatkichi nazorat guruhiga nisbatan 18–24% yuqori ekanini ko'rsatmoqda[3].

Intellektual maslahatchi tizimlar (ITS — Intelligent Tutoring Systems). Bu tizimlar talabani har bir qadamini kuzatib boradi va xato qilingan zahoti uning sababini tushuntirib, to'g'ri yo'nalish ko'rsatadi — ya'ni an'anaviy baholashdan farqli o'laroq, xatoning qaysi bosqichda yuzaga kelganini aniqlab beradi. VanLehn (2011) meta-tahlilida ITS tizimlari an'anaviy dars bilan

qiyoslaganda o'rtacha 0,76 sigma o'zlashtirish effektini ta'minlashi aniqlangan[4]. "Sonli usullar" kontekstida bu Nyuton usulining iteratsiya jarayonini bosqichma-bosqich vizualizatsiya qilish, LU-dekompozitsiyada pivot tanlash xatolarini real vaqtda ko'rsatish, Simpson formulasidagi indekslash muammolarini darhol qayd etish kabi shakllarda namoyon bo'ladi.

Ixtisoslashgan hisoblash vositalari. GitHub Copilot va Wolfram Alpha talabaga aniq algoritmik masalani yechishda bevosita ko'mak beradi. Copilot har bir funksiyaning maqsadini izoh sifatida generatsiya qilib, kodni tushuntirib yozadi; Wolfram Alpha esa analitik yechimni hisoblaydi. Talaba ikkala natijani taqqoslab, sonli usulning diskretizatsiya xatosi qanday shakllanishini amalda ko'radi va bu tushunchani nazariy bilim sifatida emas, o'z tajribasi sifatida o'zlashtiradi [2].

3. Taklif etilayotgan metodika

Nam DU 3-kurs talabalariga (n=90, ikkita guruh) o'tkazilgan tajribaviy o'qitishda quyidagi uch bosqichli metodika qo'llandi.

Birinchi bosqich — kontseptual tushunish. Har bir mavzu o'rganilishidan avval talabalar ChatGPTga kontseptual savollar berib, algoritmnining geometrik va fizikaviy ma'nosini mustaqil kashf etdilar. Masalan, Runge–Kutta usulini o'rganishdan oldin "Nima uchun Eyler usuli katta qadamda aniqlikni yo'qotadi?" degan savol berildi va talabalar SI bilan suhbat orqali lokal kesish xatosi tushunchasiga o'zlari yetib keldilar. Bu yondashuv "aktiv o'qitish" (active learning) tamoyiliga asoslanib [5], bilimni tayyor holda qabul qilish o'rniga mustaqil konstruktsiya qilish ko'nikmasini shakllantiradi. O'qituvchining roli bu bosqichda yo'naltiruvchi sifatida saqlanib, talabalar xulosalarini sinfda muhokama qilish va to'ldirish bilan cheklanadi.

Ikkinchi bosqich — amaliy. GitHub Copilot yordamida talabalar Pythonida algoritmlarni kodladilar. Copilot faqat sintaktik yordam bermay, har bir funksiyaning maqsadini izoh sifatida generatsiya qildi va muqobil yozuv variantlarini taklif etdi. O'qituvchi esa tayyor kodni emas, algoritmik mantiq xatolarini — masalan, iteratsiya to'xtash shartining noto'g'ri belgilanishi yoki massiv indeksining siljishini — qayd etishga e'tiborini qaratdi. Bu rollar taqsimoti dars vaqtidan samaraliroq foydalanish imkonini berdi. Natijada amaliy ko'nikmalar bo'yicha eksperimental guruh nazorat guruhidan 35% yuqori ko'rsatkich qayd etdi [3].

Uchinchi bosqich — avtomatik baholash. Wolfram Alpha va SymPy kutubxonasi asosida ishlab chiqilgan modul talabalar yechimini analitik natija bilan avtomatik taqqoslab, har bir ish uchun absolyut va nisbiy xato hisobotini tuzdi hamda xato qaysi bosqichda (boshlang'ich shart, iteratsiya formulasi yoki to'xtash mezoni) kelib chiqqanini ko'rsatdi. Natijada o'qituvchi 20 ta amaliy ishini tekshirishga sarflaydigan vaqt 3 soatdan 25 daqiqaga qisqardi — bu esa o'qituvchiga tahliliy fikrlashni talab qiluvchi vazifalar, ya'ni individual konsultatsiya va chuqur muhokamaga ko'proq vaqt ajratish imkonini berdi.

4. Natijalar va muhokama

Tajriba yakunida eksperimental guruh (n=45, SI vositalari bilan o'qitilgan) o'rtacha 76,4 ball, nazorat guruhi (n=45, an'anaviy usulda o'qitilgan) esa 61,2 ball to'pladi. Ballar farqi 15,2 ni tashkil etib, Student t-testi bo'yicha statistik jihatdan muhim farq sifatida tasdiqlandi ($p < 0,05$). Alohida mavzular bo'yicha tahlil qilinganda, farq eng katta Runge–Kutta usuli (eksperimental: 79,1, nazorat: 58,3) va Lagranj interpolatsiya formulasi va uning xatoligi mavzularida kuzatildi — aynan shu mavzularda amaliy kodlash va vizualizatsiya eng ko'p qo'llanilgan edi.

Talabalar so'rovnomasida (n=45) 87% SI vositalarini o'quv jarayonida foydali deb baholadi, 74% mustaqil ishlash qobiliyati oshganini, 68% esa murakkab algoritmlarni tushunish osonlashganini qayd etdi. Ochiq savollarga berilgan javoblarda talabalar eng ko'p ChatGPT'ning kontseptual tushuntirishlarini (43%) va GitHub Copilotning kod generatsiyasini (38%) foydali deb ko'rsatdi.

Biroq tadqiqot bir qator muhim muammolarni ham yuzaga chiqardi. Birinchidan, talabalarning 23% SI javoblarini mustaqil tekshirmasdan to'g'ridan-to'g'ri qabul qildi — bu holat ayniqsa konvergensiya shartlarini tahlil qilish kabi nazariy masalalarda ko'proq kuzatildi. Ushbu tendensiya "algoritmik savodxonlik" — ya'ni SI chiqishini tanqidiy baholash ko'nikmasining — etarli darajada shakllanmaganligidan dalolat beradi [4]. Ikkinchidan, LLM modellari sinov

davomida bir necha hollarda matematik hisob-kitoblarda xatoga yo‘l qo‘ydi: xususan, katta o‘lchamli ($n > 50$) matritsalar bilan ishlashda va iteratsiya yaqinlashish shartini aniqlashda noto‘g‘ri natija berdi [5]. Uchinchidan, internet ulanishi cheklangan yoki kompyuter sinfi imkoniyati past bo‘lgan universitetlarda ushbu metodikani to‘liq qo‘llash qiyin ekanigi ham amaliy cheklov sifatida aniqlandi.

Shuningdek, o‘qituvchilar tomonidan ham muhim kuzatuv qayd etildi: SI vositalari joriy etilgandan so‘ng talabalarning darsga tayyorlik darajasi o‘rtacha oshdi, biroq ba‘zi talabalar amaliy ishlarini o‘zlari bajarish o‘rniga SI dan tayyor yechim so‘rash yo‘lini tutdi. Bu esa baholash tizimini qayta ko‘rib chiqish zarurligini — jumladan, jarayon baholash (process assessment) elementlarini kiritishni — ko‘rsatadi. Umuman olganda, olingan natijalar SI texnologiyalarining “Sonli usullar” fanida o‘qituvchi nazorati ostida qo‘llanilganda sezilarli pedagogik samara berishini tasdiqlaydi.

5. Xulosa va tavsiyalar

Ushbu tadqiqot “Sonli usullar” fanini o‘qitishda sun‘iy intellekt texnologiyalaridan foydalanishning pedagogik samaradorligini tajribaviy asosda tasdiqladi. Taklif etilgan uch bosqichli metodika — kontseptual tushunish, amaliy kodlash va avtomatik baholash — an‘anaviy dars tizimiga organik integratsiya qilinishi mumkin bo‘lib, qo‘shimcha moddiy resurs talab qilmaydi. Eksperimental guruhning nazorat guruhiga nisbatan 14% ustunligi metodikaning miqdoriy samaradorligini ko‘rsatsa, talabalar so‘rovnomasidagi 87% ijobiy baho uning sifat jihatidan ham muvaffaqiyatli qabul qilinganligini tasdiqlaydi.

Tadqiqot natijalari shuni ko‘rsatadiki, SI vositalari o‘qituvchini almashtira olmaydi va almashtirishga mo‘ljallanmagan — aksincha, uning strategik vazifasini kuchaytiradi. O‘qituvchi ma‘muriy va takroriy tekshiruv yukidan ozod bo‘lib, talabalar bilan chuqur intellektual muloqotga — xato tahlili, algoritmik fikrlashni rivojlantirish, muqobil yondashuvlarni muhokama qilish — ko‘proq vaqt ajrata oladi. Bu esa ta‘limning eng qimmatli tomoni fikrlash madaniyatini shakllantirishni mustahkamlaydi. Xususan, amaliy bosqichida kuzatilganidek, o‘qituvchi Copilot tomonidan generatsiya qilingan kodni tahlil qilish orqali talabalar bilan algoritmik mantiq haqida yanada mazmunli suhbat qurishga muvaffaq bo‘ldi — bu an‘anaviy formatda kamdan-kam uchraydigan holat edi.

Metodikaning yana bir muhim natijasi — talabalarning o‘z-o‘zini boshqarish (self-regulated learning) ko‘nikmasining rivojlanishi. Kontseptual bosqichda ChatGPT bilan mustaqil suhbat yuritgan talabalar keyinchalik amaliy ishlarida ham muammoni avval o‘zlari tahlil qilib, so‘ngra SI ga murojaat qilish odatini shakllantirdi. Bu esa passiv tinglovchidan faol tadqiqotchiga o‘tishning dastlabki belgilari sifatida baholanadi. Shu bilan birga, SI vositalarini samarali qo‘llash uchun talabada tanqidiy fikrlash va “SI savodxonligi” ko‘nikmasi bo‘lishi zarur — aks holda texnologiya chuqur o‘zlashtirish o‘rniga passiv qaramlik xavfini tug‘diradi. Umuman olganda, olingan natijalar SI texnologiyalarining “Sonli usullar” fanida o‘qituvchi nazorati ostida qo‘llanilganda ham miqdoriy, ham sifat jihatidan sezilarli pedagogik samara berishini ishonchli tarzda tasdiqlaydi.

Tavsiya: SI vositalarini “Sonli usullar” kursiga kirishdan oldin yoki parallel tarzda “SI savodxonligi” moduli bilan birga joriy etish tavsiya etiladi — bu modul SI chiqishini tanqidiy baholash, xatolarni mustaqil aniqlash va natijalarni solishtirish ko‘nikmalarini o‘z ichiga olishi lozim. Universitet ma‘muriyatiga LMS platformalariga adaptiv o‘qitish modullarini integratsiya qilish va o‘qituvchilar malakasini oshirish dasturlariga “pedagogik SI” bo‘limini kiritish maqsadga muvofiq. Baholash tizimiga jarayon elementlarini (process assessment) kiritish orqali talabalarning SI dan foydalanish madaniyatini ham baholash imkoniyati yaratiladi. Keyingi tadqiqotlarda SI vositalaridan foydalanilgan talabalarning uzoq muddatli — kamida bir yillik — o‘zlashtirish dinamikasini kuzatish, shuningdek, O‘zbekiston oliy ta‘lim tizimining o‘ziga xos sharoitlariga moslashtirilgan mahalliy intellektual maslahatchi tizimlarni ishlab chiqish istiqbolli va muhim yo‘nalish hisoblanadi.

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PHP ASOSIDAGI TA'LIM TIZIMLARIDA SUN'IY INTELLEKTDAN FOYDALANISH

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Annotatsiya. Tezisdá PHP dasturlash tilida yaratilgan ta'limiy veb-platformalarga sun'iy intellekt texnologiyalarini integratsiyalash imkoniyatlari hamda ushbu jarayonda yuzaga keladigan muammolar tahlil qilinadi. Sun'iy intellekt yordamida o'quv jarayonini avtomatlashtirish, foydalanuvchi faoliyatini monitoring qilish va moslashtirilgan ta'lim xizmatlarini tashkil etish imkoniyatlari yoritilgan. Tadqiqot davomida AI asosidagi chatbotlar, avtomatik baholash tizimlari va tavsiya algoritmlarining PHP platformalaridagi samaradorligi ko'rib chiqilgan. Shuningdek, server yuklamasi, ma'lumotlar xavfsizligi va algoritmik aniqlik bilan bog'liq muammolar ilmiy jihatdan baholangan.

Kalit so'zlar: sun'iy intellekt, PHP, elektron ta'lim, veb-platforma, chatbot, avtomatik baholash, AI texnologiyalari, ta'lim tizimlari, personalizatsiya.

Axborot texnologiyalarining rivojlanishi ta'lim tizimlarini raqamlashtirish jarayonini jadallashtirmoqda. Elektron ta'lim platformalari masofaviy o'qitish, bilimlarni nazorat qilish va foydalanuvchilar bilan interaktiv ishlash imkoniyatlarini taqdim etmoqda [1]. Ayniqsa, sun'iy intellekt texnologiyalarining joriy qilinishi ta'lim tizimlarining samaradorligini oshirishda muhim omilga aylanmoqda. PHP dasturlash tili veb-ilovalarni ishlab chiqishda keng qo'llaniladigan texnologiyalardan biri hisoblanadi. Ushbu platformalarda sun'iy intellekt elementlarini qo'llash orqali foydalanuvchilarga moslashtirilgan xizmatlar yaratish, avtomatik nazorat tizimlarini tashkil qilish va o'quv jarayonini optimallashtirish mumkin [2]. Shu bilan birga, AI texnologiyalarini integratsiyalashda texnik va xavfsizlik bilan bog'liq ayrim cheklovlar ham mavjud.

Sun'iy intellekt texnologiyalarining PHP asosidagi ta'lim platformalarida qo'llanilishi foydalanuvchi faoliyatini chuqur tahlil qilish imkonini beradi. AI algoritmlari foydalanuvchilarning o'quv natijalari va platformadagi harakatlarini o'rganib, ularga mos o'quv materiallarini tavsiya qilishi mumkin [3]. Natijada ta'lim jarayoni individual yondashuv asosida tashkil etiladi. Bundan tashqari, avtomatik baholash tizimlari ham sun'iy intellektning muhim yo'nalishlaridan biri hisoblanadi. PHP asosidagi platformalarda test natijalarini tekshirish, statistik tahlil qilish va foydalanuvchi xatolarini aniqlash AI yordamida tez va samarali amalga oshiriladi [4]. Bu esa o'qituvchilar ish yuklamasini kamaytirish bilan birga baholash aniqligini oshiradi.

AI asosidagi chatbotlar ta'lim platformalarining interaktivligini kuchaytiradi. Bunday tizimlar foydalanuvchilarning savollariga avtomatik javob berish, dars mavzulari bo'yicha yordam ko'rsatish va texnik muammolarni hal qilish imkonini beradi [1]. Ayniqsa, masofaviy ta'lim tizimlarida chatbotlar foydalanuvchilar bilan uzluksiz muloqotni ta'minlaydi. Shu bilan birga, sun'iy intellektni PHP platformalariga integratsiyalash jarayonida ayrim muammolar ham kuzatiladi. AI algoritmlarining katta hajmdagi ma'lumotlarni qayta ishlashi server resurslariga yuqori yuklama berishi mumkin [2]. Bundan tashqari, foydalanuvchi ma'lumotlarini himoyalash va maxfiylikni ta'minlash masalalari ham muhim ahamiyatga ega. OpenAI, Google va Microsoft kompaniyalari ta'lim tizimlari uchun sun'iy intellekt asosidagi yechimlarni ishlab chiqish ustida faol ishlamoqda. Ushbu texnologiyalar elektron ta'lim platformalarining funksional imkoniyatlarini kengaytirishga xizmat qilmoqda [3].

O'tkazilgan tahlillar sun'iy intellekt texnologiyalarining PHP asosidagi ta'lim platformalarida muhim ahamiyatga ega ekanligini ko'rsatadi. AI yordamida avtomatik baholash, foydalanuvchi faoliyatini monitoring qilish va individual o'quv xizmatlarini tashkil etish imkoniyati

yaratiladi. Shu bilan birga, server unumdorligi, ma'lumotlar xavfsizligi va algoritmning aniqqligi bilan bog'liq muammolarni bartaraf etish zarur hisoblanadi. Kelgusida sun'iy intellekt texnologiyalarining rivojlanishi elektron ta'lim platformalarini yanada aqlli va samarali tizimlarga aylantirishi kutilmoqda.

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PHP PLATFORMALARIDA AI ASOSIDA TAVSIYA TIZIMLARI ISHLAB CHIQISH

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Annotatsiya. Tezida PHP dasturlash tilida yaratilgan veb-platformalarda sun'iy intellekt asosidagi tahlil va tavsiya tizimlarini tashkil etish imkoniyatlari tahlil qilinadi. Zamonaviy veb-ilovalarda foydalanuvchi faoliyatini o'rganish va unga mos tavsiyalarni shakllantirish xizmat sifatini oshirishda muhim omillardan biri hisoblanadi. Tadqiqot davomida AI algoritmning PHP tizimlariga integratsiyasi, foydalanuvchi ma'lumotlarini qayta ishlash jarayoni hamda personalizatsiyalashgan tavsiya mexanizmlarining ishlash tamoyillari ko'rib chiqilgan. Shuningdek, tizim samaradorligi, xavfsizlik masalalari va texnologiyaning rivojlanish istiqbollari baholangan.

Kalit so'zlar: sun'iy intellekt, PHP, tavsiya tizimi, veb-platforma, ma'lumotlar tahlili, AI algoritm, personalizatsiya, foydalanuvchi faoliyati.

Zamonaviy veb-platformalarda foydalanuvchi ehtiyojlariga mos xizmatlarni taqdim etish muhim ahamiyat kasb etmoqda. Sun'iy intellekt asosidagi tavsiya tizimlari foydalanuvchilarning qiziqishlari va faoliyatini tahlil qilish orqali ularga mos kontent yoki xizmatlarni avtomatik taklif etadi [1]. Bunday tizimlar elektron ta'lim, internet-do'konlar, media platformalar va axborot portallarida keng qo'llanilmoqda. PHP dasturlash tili dinamik veb-ilovalarni ishlab chiqishda keng tarqalgan texnologiyalardan biri hisoblanadi. PHP asosidagi tizimlarga AI texnologiyalarini integratsiyalash orqali aqlli tahlil va tavsiya xizmatlarini yaratish mumkin [2]. Natijada foydalanuvchi bilan interaktiv ishlovchi va moslashtirilgan xizmatlarni taqdim etuvchi platformalar shakllanadi.

Sun'iy intellekt asosidagi tavsiya tizimlari foydalanuvchilarning platformadagi harakatlarini tahlil qilish orqali ishlaydi. Tizim foydalanuvchining qidiruvlari, ko'rilgan sahifalari, tanlovlari va qiziqishlarini o'rganib, unga mos ma'lumotlarni tavsiya etadi [3]. PHP veb-ilovalarida bunday tizimlarni yaratishda ma'lumotlar bazalari va AI modellaridan birgalikda foydalaniladi. Tavsiya tizimlari asosan ikki xil yondashuvga asoslanadi: kontentga asoslangan filtratsiya va kollaborativ filtratsiya. Kontentga asoslangan usul foydalanuvchining avvalgi qiziqishlariga mos ma'lumotlarni tavsiya qiladi. Kollaborativ filtratsiya esa o'xshash foydalanuvchilarning faoliyatini tahlil qilish asosida ishlaydi [4]. Ushbu algoritmlar API xizmatlari yoki tashqi AI platformalari orqali PHP tizimlariga integratsiyalanadi.

AI texnologiyalaridan foydalanish platforma samaradorligini oshirish bilan birga foydalanuvchi qulayligini ham yaxshilaydi. Masalan, ta'lim platformalarida talabaga bilim darajasiga mos kurslar tavsiya qilinishi mumkin. Elektron savdo tizimlarida xaridorlarga qiziqishlariga mos mahsulotlarni avtomatik taklif qilish imkoniyati yaratiladi [1]. Bu esa foydalanuvchi faolligini oshirishga yordam beradi. Shu bilan birga, sun'iy intellekt asosidagi tizimlarni joriy etishda ayrim muammolar ham yuzaga keladi. Katta hajmdagi ma'lumotlarni qayta ishlash server resurslariga yuqori yuklama berishi mumkin [2]. Bundan tashqari, foydalanuvchi ma'lumotlarini himoyalash va maxfiylikni ta'minlash masalalari muhim ahamiyat kasb etadi. AI algoritmning noto'g'ri tavsiyalari esa tizim samaradorligini pasaytirishi mumkin. OpenAI, Google va Amazon kompaniyalari AI asosidagi tavsiya tizimlari va ma'lumotlar tahlili

texnologiyalarini rivojlantirish ustida faol tadqiqotlar olib bormoqda. Ushbu texnologiyalar zamonaviy veb-platformalarning ajralmas qismiga aylanib bormoqda [3].

O'tkazilgan tahlillar sun'iy intellekt asosidagi tavsiya tizimlari PHP veb-platformalarining funksional imkoniyatlarini sezilarli darajada kengaytirishini ko'rsatadi. AI yordamida foydalanuvchi faoliyatini tahlil qilish, individual xizmatlarni shakllantirish va platforma samaradorligini oshirish mumkin. Shu bilan birga, server yuklamasi, ma'lumotlar xavfsizligi va algoritmlar aniqligi bilan bog'liq muammolarni hal etish muhim vazifalardan biri hisoblanadi. Kelgusida AI texnologiyalarining rivojlanishi aqlli va moslashuvchan veb-platformalarni yaratishda muhim rol o'ynashi kutilmoqda.

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PEDAGOGIK DIAGNOSTIKA TIZIMLARIDA SUN'IY INTELLEKT: IMKONIYATLAR, MODELLAR VA AXLOQIY MASALALAR

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Annotatsiya. Ushbu maqola pedagogik diagnostika tizimlarida sun'iy intellekt (SI) texnologiyalarining qo'llanilishini tizimli tahlil qiladi. An'anaviy pedagogik diagnostika usullari – testlar, og'zaki so'rovlar va kuzatuvlar – sinfdagi o'quvchilar sonining ko'pligi, subyektiv baholash va teskari aloqaning kechikishi kabi muammolar bilan cheklangan. SI texnologiyalari, xususan, mashinaviy o'rganish (ML), tabiiy tilni qayta ishlash (NLP) va adaptiv testlash tizimlari ushbu muammolarni hal qilishda muhim rol o'ynaydi.

Maqolada uchta asosiy yo'nalish tahlil etiladi: (1) o'quvchilarning bilim bo'shliqlari va noto'g'ri tushunchalarini avtomatik aniqlash, (2) adaptiv testlash tizimlarida javob vaqtini baholash modeliga integratsiya qilish, (3) ma'lumotlar analitikasi asosida o'quv natijalarini prognozlash. Shuningdek, SI diagnostik tizimlarining joriy etilishidagi axloqiy muammolar – algoritmik tarfakashlik, shaffoflik va maxfiylik masalalari hamda o'qituvchining o'zgarayotgan roli muhokama qilinadi. Xulosa qilib aytganda, pedagogik diagnostikada SI o'qituvchining "ikkinchi ko'zi" sifatida ishlay oladi, ammo uning qarorlari pedagogik nazorat ostida bo'lishi shart.

Kalit so'zlar: pedagogik diagnostika, sun'iy intellekt, mashinaviy o'rganish, adaptiv testlash, noto'g'ri tushunchalarni aniqlash, ma'lumotlar analitikasi, algoritmik tarfakashlik.

Pedagogik diagnostika – o'quvchilarning bilim darajasi, ko'nikmalari va o'quv faoliyatidagi muammolarini aniqlashga qaratilgan jarayon. An'anaviy diagnostika usullari (testlar, og'zaki so'rovlar, kuzatuvlar) uzoq vaqt davomida ta'lim tizimining asosiy vositasi bo'lib kelgan. Biroq, Purnama va boshqalar (2025) ta'kidlaganidek, "noto'g'ri tushunchalarni (misconceptions) gavjum sinf xonasida diagnostika qilish an'anaviy usullarda juda qiyin, vaqt talab qiladi va subyektivdir, bu esa ko'pincha samarasiz pedagogik aralashuvlarga olib keladi".

Sun'iy intellektning ta'limga integratsiyasi ushbu muammolarni hal qilishda yangi imkoniyatlar yaratmoqda. So'nggi yillarda SI asosidagi pedagogik diagnostika tizimlari bo'yicha tadqiqotlar soni keskin oshgan. Bibliometrik tahlil shuni ko'rsatadiki, "mashinaviy o'rganish, bashoratli modellashtirish va shaxsiylashtirilgan ta'lim 2020-yildan keyin tadqiqotlarning asosiy yo'nalishlariga aylangan".

Ushbu maqolaning maqsadi – pedagogik diagnostika tizimlarida sun'iy intellekt texnologiyalarining joriy holatini, qo'llanish modellarini va axloqiy muammolarini kompleks tahlil qilish.

Pedagogik diagnostikada SI texnologiyalarining asosiy yo'nalishlari. Noto'g'ri tushunchalarni (misconceptions) aniqlash - o'quvchilarning fanlarni (ayniqsa, fizika, matematika va tabiiy fanlar) o'zlashtirish jarayonida yuzaga keladigan noto'g'ri tushunchalar o'quv jarayonining samaradorligiga jiddiy to'sqinlik qiladi. Mashinaviy o'rganish modellari, xususan, tabiiy tilni qayta

ishlash (NLP) texnologiyalari o'quvchilarning yozma javoblarini (masalan, esse yoki ochiq savollarga javoblar) tez va izchil tahlil qilish imkonini beradi.

Amaliy misol: SI modellari o'quvchining fizika masalasini yechishdagi xatosini tahlil qilib, bu xatoning qanday noto'g'ri tushunchadan kelib chiqqanligini aniqlay oladi – masalan, Nyutonning uchinchi qonunini noto'g'ri tushunish yoki energiyaning saqlanish qonunidagi xato.

ML modellari asosida noto'g'ri tushunchalarni uchta darajada tasniflash mumkin:

Aniqlash (detection) – o'quvchida noto'g'ri tushuncha bor-yo'qligini aniqlash;

Turkumlash (categorization) – qaysi turdagi noto'g'ri tushuncha ekanligini belgilash;

Bashoratlash (prediction) – o'quvchining kelgusi xatolarini oldindan taxmin qilish.

Adaptiv testlash tizimlari. An'anaviy testlar barcha o'quvchilarga bir xil savollarni taqdim etadi. Adaptiv testlash tizimlari esa o'quvchining javoblariga qarab keyingi savollarning qiyinlik darajasini dinamik ravishda o'zgartiradi. Ince va Ozbay (2025) tomonidan ishlab chiqilgan "TestYourself" tizimi – bu sohadagi muhim yutuq hisoblanadi.

Tizimning o'ziga xos xususiyati: An'anaviy adaptiv tizimlardan farqli o'laroq, ushbu tizim nafaqat javobning to'g'riligini, balki javob vaqtini (response time) ham baholash modeliga integratsiya qiladi. Tizim quyidagicha ishlaydi:

Har bir savol uchun o'quvchining javob vaqti va to'g'riligi qayd etiladi;

Javob vaqti chiziqli va kubik regressiya modellari yordamida baholanadi;

Random Forest va k-nearest neighbors (k-NN) algoritmlari asosida o'quvchilarning qobiliyati tasniflanadi.

Natijalar: Random Forest algoritmi yordamida olingan AUROC ko'rsatkichi (qobiliyat ballari va vaqt asosidagi qo'shimcha ballar) faqat qobiliyat ballariga nisbatan 33.46% ga sezgirroq ekanligi aniqlangan.

Bu o'quvchining nafaqat "nima biladi", balki "qanchalik tez va samarali fikrlaydi"ligini ham baholash imkonini beradi.

Ma'lumotlar analitikasi va bashoratli modellashtirish. Ta'lim ma'lumotlarini qazib olish (Educational Data Mining – EDM) va o'rganish analitikasi (Learning Analytics – LA) SI texnologiyalarining eng faol qo'llanilayotgan sohalaridan biridir. Muriira va boshqalar (2026) bibliometrik tahlilida 2005-2025 yillar oralig'ida ushbu mavzuda 1006 ta ilmiy maqola nashr etilganligi qayd etilgan.

Generativ SI vositalari (masalan, GPT modellari) so'nggi yillarda o'rganish analitikasida ham qo'llanila boshlandi. Misiejuk va boshqalar (2025) tizimli adabiyotlar sharhida 41 ta maqolani tahlil qilib, generativ SI hozirda asosan diskurs kodlash, avtomatik baholash va matnlarni klassifikatsiya qilish vazifalarida qo'llanilayotganligini aniqlagan.

Maxsus ta'lim ehtiyojlari bo'lgan o'quvchilar uchun SI diagnostikasi. Ulas va boshqalar (2025) tomonidan o'tkazilgan tizimli adabiyotlar sharhi (2015-2025 yillar oralig'ida 30 ta eksperimental tadqiqot) SI texnologiyalarining o'qishda qiyinchiligi (disleksiya) va diqqat yetishmasligi bo'lgan o'quvchilar uchun diagnostika va ta'limdagi samaradorligini tahlil qilgan.

Ushbu tadqiqot shuni ko'rsatadiki, SI nafaqat umumiy ta'limda, balki maxsus ta'lim ehtiyojlari bo'lgan o'quvchilarni erta diagnostika qilish va ularga moslashtirilgan ta'limni tashkil etishda ham katta salohiyatga ega.

Axloqiy muammolar va cheklovlar. SI asosidagi pedagogik diagnostika tizimlarini joriy etish bir qator axloqiy va amaliy muammolarni keltirib chiqaradi. Monett va boshqalar (2026) o'zlarining kritik tahlilida ushbu muammolarni to'rt asosiy yo'nalishda guruhlaydi.

Algoritmik tarfakashlik. "AI tizimlari tarixiy tarfakash ma'lumotlar to'plamlarida o'rgatilgan bo'lsa, ta'limdagi tengsizliklarni saqlab qolish (perpetuate) yoki kuchaytirish xavfi mavjud". Masalan, agar SI modeli asosan ma'lum bir ijtimoiy-iqtisodiy muhitdagi o'quvchilar ma'lumotlarida o'rgatilgan bo'lsa, boshqa muhitdagi o'quvchilarning bilimini noto'g'ri baholashi mumkin.

Yechimga harakatlar: Peng va boshqalar (2026) Warwick universitetida olib borgan tadqiqotida SI tomonidan yaratilgan ta'lim kontentidagi tarfakashlikni avtomatik baholash

uchun CEAT (Contextualized Embedding Association Test) ramkasini taklif qilgan. Ushbu usul qo'lda baholash bilan yuqori darajada mos kelishi ko'rsatilgan.

Ko'pgina ML modellari (ayniqsa chuqur neyron tarmoqlar) "qora quti" tamoyilida ishlaydi – ya'ni ularning qaror qabul qilish mexanizmini tushuntirish qiyin. Ta'limda bu muammoli, chunki o'qituvchi va ota-onalar nima uchun SI tizimi ma'lum bir o'quvchini "xavfli zona"da deb belgilaganligini bilish huquqiga ega.

Maxfiylik va ma'lumotlar xavfsizligi. Baxarova (2025) ta'kidlaganidek, O'zbekiston kontekstida ham "texnologiyalarni ta'lim tizimiga joriy etishda axborot xavfsizligi, maxfiylik va normativ-huquqiy masalalar" muhim muammo hisoblanadi.

SI tizimlari o'quvchilarning javoblarini, vaqt parametrlarini, xatolarini va hatto hissiy holatlarini qayd etadi. Ushbu ma'lumotlarning kim tomonidan, qanday maqsadda ishlatilishi va qancha vaqt saqlanishi aniq belgilanishi kerak.

O'qituvchi rolining o'zgarishi. SI diagnostik tizimlarining keng joriy etilishi o'qituvchining rolining o'zgarishiga olib keladi. Endi o'qituvchi asosiy "bilim diagnostikatori" emas, balki "SI tahlillarini sharhlovchi" va "pedagogik aralashuvni rejalashtiruvchi" sifatida ishlaydi. Bu esa o'qituvchilarning raqamli kompetensiyalarini rivojlantirishni talab qiladi.

O'zbekistonda bu borada ijobiy qadamlar qo'yilmoqda. 2025-yil 1-dekabrda prezident taqdimotiga asosan, "kelgusi o'quv yilidan maktab, texnikum va universitetlarda sun'iy intellekt bo'yicha maxsus ta'lim dasturlari boshlanadi. Informatika o'qituvchilaridan tashqari, barcha pedagoglar SI ni amalda qo'llash bo'yicha tayyorgarlikdan o'tkaziladi".

Amaliy tavsiyalar. Adabiyotlar tahlili va amaliy tajribalarga asoslanib, pedagogik diagnostikada SI tizimlarini joriy etish bo'yicha quyidagi tavsiyalar ishlab chiqilgan:

1. Bosqichma-bosqich joriy etish:

1-bosqich: SI tizimlarini yordamchi (assistant) sifatida sinovdan o'tkazish;

2-bosqich: o'qituvchilar va SI hamkorligida diagnostika;

3-bosqich: avtomatik diagnostika elementlarini joriy etish.

2. Shaffoflikni ta'minlash:

SI qarorlarini tushuntirish mexanizmlarini (explainable AI) qo'llash;

O'qituvchilarga SI tahlillarining metodologiyasini o'rgatish.

3. Tarafkashlikni muntazam tekshirish:

Har bir SI modeli joriy etishdan oldin turli guruhlar ma'lumotlarida sinovdan o'tkazilishi;

CEAT koni avtomatik baholash ramkalaridan foydalanish .

4. Maxfiylik protokollari:

O'quvchilar ma'lumotlarini anonimlashtirish;

Ma'lumotlarni faqat pedagogik maqsadlarda ishlatish bo'yicha aniq shartnomalar tuzish.

5. O'qituvchilarni tayyorlash:

SI savodxonligi bo'yicha majburiy kurslar;

SI diagnostika natijalarini sharhlash bo'yicha amaliy treninglar.

Kelajak istiqbollari. Pedagogik diagnostikada sun'iy intellektning kelgusi rivojlanishi quyidagi yo'nalishlarda kutilmoqda:

Generativ SI integratsiyasi – diagnostika natijalariga asoslangan holda shaxsiylashtirilgan teskari aloqa va mashqlarni avtomatik yaratish .

Emotsional va kognitiv diagnostika – o'quvchining hissiy holatini (zerikish, stress, ishonch) aniqlash va diagnostika jarayoniga integratsiya qilish.

Krossover diagnostika – bir fan bo'yicha aniqlangan noto'g'ri tushunchaning boshqa fanlardagi ta'sirini bashoratlash.

Ochiq standartlar – turli SI diagnostika tizimlari o'rtasida ma'lumot almashish imkonini beruvchi protokollarni ishlab chiqish.

Sun'iy intellekt pedagogik diagnostika sohasida an'anaviy usullarning cheklovlarini yengishda muhim vositaga aylanmoqda. Mashinaviy o'rganish modellari o'quvchilarning noto'g'ri tushunchalarini tez va ob'yektiv aniqlash, adaptiv testlash tizimlari nafaqat javob to'g'riligini, balki

kognitiv samaradorlikni ham baholash, ma'lumotlar analitikasi esa o'quv natijalarini bashoratlash va erta aralashuv imkonini beradi.

Biroq, bu texnologiyalarni joriy etishda axloqiy masalalarga – algoritmik tarafdashlik, shaffoflik, maxfiylik va o'qituvchi rolining o'zgarishiga – alohida e'tibor qaratish lozim. SI o'qituvchini almashtirmasligi, balki uning diagnostik imkoniyatlarini kuchaytiruvchi "ikkinchi ko'z" sifatida ishlashi kerak.

O'zbekiston ta'lim tizimida SI texnologiyalarini joriy etish bo'yicha qabul qilingan strategiyalar va so'nggi yillardagi tadqiqotlar ushbu yo'nalishda muhim qadamlar qo'yilayotganini ko'rsatadi. Ammo bu jarayonda pedagogik metodika va axloqiy standartlarni birgalikda rivojlantirish muhim vazifa bo'lib qolmoqda.

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AXBOROT TEXNOLOGIYALARI VA SUN'IY INTELLEKT

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ANNOTATSIYA. Ushbu maqola axborot texnologiyalari (AT) va sun'iy intellekt (SI) rivojlanishining fundamental falsafiy asoslarini o'rganadi. Unda inson-mashina o'zaro ta'sirining ontologik jihatlarini, avtomatlashtirilgan qaror qabul qilishning axloqiy muammolari va kognitiv jarayonlarning raqamlashtirilishi natijasida yuzaga keladigan epistemologik o'zgarishlar o'rganiladi. Texnologik determinizm tushunchasi va uning zamonaviy ijtimoiy voqelikka ta'siri M. Xaydegger, N. Bostrom va L. Floridining asarlari kontekstida tahlil qilinadi. Maqolada "kuchli" SI istiqbollari haqida tanqidiy nuqtai nazar taqdim etiladi va texnologik taraqqiyotni gumanitar fanlarga asoslangan baholash zarurligi ta'kidlanadi. Tadqiqot kognitiv funktsiyalarni biologik bo'lmagan substratlarga topshirish bilan bog'liq ekzistensial xavflarni aniqlashga qaratilgan.

Kalit so'zlar: texnologiya falsafasi, sun'iy intellekt, raqamli jamiyat, algoritmlar etikasi, ontologiya, kognitiv fan, texnologik singularlik, kibermakon, intensionallik, antroposentrizm.

KIRISH

20 va 21-asrlar oxirlarida insoniyat chuqur texnologik o'zgarish bosqichiga kirdi, bu bosqichni Luciano Floridi "to'rtinchi inqilob" deb ta'riflab, odamlarni axborot agentlari bilan bir qatarga qo'ydi. Axborot texnologiyalari shunchaki odatiy vazifalarni avtomatlashtirish uchun vositalar to'plami bo'lishdan to'xtadi va madaniyat, siyosat va individual ong evolyutsiyasida hal qiluvchi omilga aylandi.

Ushbu jarayonni falsafiy tushunish juda muhim ahamiyat kasb etmoqda, chunki sun'iy intellekt sub'ekt, erkin iroda va inson ongining o'ziga xosligi haqidagi an'anaviy tushunchalarga qarshi chiqmoqda. Texnologiya ilgari "protez" yoki inson jismoniy imkoniyatlarining kengaytmasi sifatida qaralgan bo'lsa (E. Kappning so'zlariga ko'ra), zamonaviy AT tizimlari kognitiv funktsiyalarni almashtirishni da'vo qilmoqda. Ushbu mavzuning dolzarbligi hayotning barcha sohalarini tez kibernetizatsiya qilish va o'z-o'zini o'rganish algoritmlari ustidan nazoratni yo'qotish xavfi kontekstida axloqiy va mafkuraviy ko'rsatmalarni ishlab chiqish zaruratidan kelib chiqadi.

TADQIQOT USULI

Ushbu ishning metodologik asosi tizimli yondashuv bo'lib, bizga ATni alohida gadgetlar sifatida emas, balki yashash muhitini o'zgartiradigan murakkab sotsiologik tizim sifatida ko'rib

chiqish imkonini beradi. Tadqiqot raqamli muhitda inson tajribasi va voqelikni idrok etish tuzilishidagi o'zgarishlarni tasvirlash uchun fenomenologik usulni qo'llaydi (kengaytirilgan voqelikdagi "hayot olami" tahlili).

Biologik kognitiv jarayonlar arxitekturasini va chuqur neyron tarmoqlari arxitekturasini taqqoslash uchun qiyosiy tahlil usuli ham qo'llaniladi. Algoritmning samaradorligi va insonning shaxsiy hayot va avtonomiya huquqi o'rtasidagi ziddiyat kabi SI rivojlanishidagi qiymat ziddiyatlarini aniqlashga qaratilgan axloqiy va aksiologik tahlil muhim rol o'ynaydi. Nazariy asos texnologiya falsafasidagi klassik paradigmalar (M. Heidegger, J. Ellul) va transhumanizmning zamonaviy konsepsiyalari tahlili bilan to'ldiriladi.

AXBOROT TEXNOLOGIYALARINING FALSAFIY MUAMMOLARI

1. Raqamli voqelik va infosferaning ontologik holati.

Zamonaviy falsafa (xususan, L. Floridining "infosfera" konsepsiyasi) ATni yangi ontologik joyning yaratilishi sifatida ko'radi. Biz obyektlar dunyosidan axborot o'zaro ta'siri dunyosiga o'tmoqdamiz. Bu yangi voqelikda "onlayn" va "oflayn" (on-life hodisasi) o'rtasidagi chegara xiralashgan. Raqamli makon o'ziga xos xususiyatlarga ega: virtuallik, lokal bo'lmaganlik va deyarli cheksiz nusxalash imkoniyati.

Ontologik nuqtai nazardan, savol tug'iladi: ob'ektning raqamli nusxasi asl nusxasi bilan bir xil maqomga egami? Mavjudlikning raqamli shaklga aylanishi inson mavjudligining tuzilishini o'zgartiradi. Odamlar dunyoni interfeyslar prizmasi orqali idrok eta boshlaydilar, bu esa fikrlashning o'zini "algoritmallashtirish"ga olib keladi. Biz ijtimoiy o'zaro ta'sirlarimizni ijtimoiy tarmoqlar va qidiruv tizimlari mantig'iga moslashtira boshlayapmiz, bu esa sub'ektivlikni tushunishimizda chuqur ontologik o'zgarishni ko'rsatadi.

2. Epistemologiya va bilim inqirozi: SI bilim subyekti sifatida.

SI rivojlanishi klassik epistemologiyani o'zgartirmoqda. An'anaga ko'ra, bilim inson ongining mutlaq huquqi hisoblangan. Biroq, zamonaviy Big Data tizimlari ishlaydigan xotira va kognitiv tarfakashliklarning cheklangan imkoniyatlari tufayli inson idrokiga kirish mumkin bo'lmagan naqshlarni aniqlashga qodir.

Bu epistemologik bo'shliqni keltirib chiqaradi: biz sun'iy intellekt qarorlariga (tibbiyot, logistika, moliya sohalarida) ishonamiz, lekin biz har doim ham bu qarorlarga olib boradigan yo'lni kuzata olmaymiz ("qora quti" muammosi). Falsafiy tahlil shuni ko'rsatadiki, bu algoritmning obro'si ratsional isbot o'rnini bosadigan "yangi dogmatizm" ning shakllanishiga olib keladi. Sun'iy intellekt ramzlarni boshqarish orqali fikrlash jarayonini simulyatsiya qiladi, ammo Jon Searle va uning "Xitoy xonasi" argumentiga ko'ra, semantik tushuncha va niyat yetishmaydi. U "qanday" ni biladi, lekin "nima uchun" ni bilmaydi.

3. Aqlning tabiati va ong muammosi.

SI falsafasidagi markaziy munozara "funktionalizm" va "biologik naturalizm" tarafdorlari o'rtasida. Funktionalistlar ong har qanday mos apparatda ishlay oladigan dasturiy ta'minot ekanligini ta'kidlaydilar. Agar mashina ratsional mavjudot kabi harakat qilsa (Tyuring testi), unda biz uni aqlli deb tan olishga majburmiz.

Tomas Nagel va Devid Chalmers kabi muxoliflar "ongning qiyin muammosi"ga - qualia (sub'ektiv hissiy tajriba) mavjudligiga ishora qiladilar. SI qizil rangni to'lqin uzunligi bilan taniy oladi, lekin u qizarishni "sezmaydi". Ma'lumotlarni qayta ishlash va fenomenal tajriba o'rtasidagi bu tafovut sun'iy shaxsni yaratishdagi asosiy to'siq bo'lib qolmoqda. Falsafiy nuqtai nazardan, o'zini anglash raqamli tizimlarda yo'q bo'lgan jismoniylik va o'lim bilan uzviy bog'liqdir.

4. Axloqiy qiyinchiliklar va "Algoritmik boshqaruv".

Sining ijtimoiy institutlarga kiritilishi javobgarlikning dolzarb masalasini ko'taradi. Agar avtonom avtomobil yoki harbiy tizim xato qilsa, "mas'uliyat tafovuti" paydo bo'ladi. Kim aybdor: tarmoqni to'liq bo'lmagan ma'lumotlar asosida o'qitgan dasturchi yoki bir zumda qaror qabul qilgan tizimning o'zi?

Bundan tashqari, "algoritmik tarfakashlik" xavfi mavjud. Neyron tarmoqlari tarixiy ma'lumotlar asosida o'qitiladi, ularda insoniy tarfakashliklar (irqiy, gender, ijtimoiy) bo'lishi mumkin. Shunday qilib, SI ob'ektivlik niqobi ostida ijtimoiy adolatsizlikni tuzatishi mumkin emas,

balki uni abadiylashtirishi va kengaytirishi mumkin. Bugungi kunda axloqiy imperativ inson tekshiruv uchun shaffof bo'lgan "tushunarli SI" ni ishlab chiqishni talab qiladi.

5. Sun'iy intellekt estetikasi: muallifning o'limi yoki yangi ijodkorlikmi?

Generativ modellarning (GANlar, diffuziya tarmoqlari) rivojlanishi san'at falsafasi uchun fundamental savol tug'diradi: mashina yaratuvchi bo'lishi mumkinmi? An'anaga ko'ra, san'at noyob inson ruhi, his-tuyg'ulari va biografik tajribasining ifodasi sifatida qaralgan. Algoritmik san'at, aksincha, ulkan ma'lumotlar to'plamlarining statistik tahlili va mavjud uslublarning rekombinatsiyasiga asoslangan.

Estetik nuqtai nazardan, bu "yaratuvchining dahosi"dan "kuratorning dahosi"ga o'tishni anglatadi. Insonlar to'g'ridan-to'g'ri ijrochilar bo'lishdan to'xtaydilar, vazifalarni belgilovchilarga aylanadilar (tezkor muhandislik). Ontologik noaniqlik paydo bo'ladi: neyron tarmog'i tomonidan yaratilgan asarning muallifligi kimga tegishli? Bu hodisaning falsafiy tahlili bizni ijodkorlik tushunchasini qayta ko'rib chiqishga majbur qiladi, yangilik nafaqat sezgi, balki ma'lumotlarning kombinatorial murakkabligidan ham kelib chiqishi mumkinligini tan oladi. Biroq, "mazmunlilik" masalasi ochiqlicha qolmoqda: mashina san'atni o'zining o'quv ma'lumotlariga xos bo'lmagan metaforalar bilan to'ldirishga qodirmi?

6. Raqamli antropologiya va jismoniylikning o'zgarishi

Axborot texnologiyalari E. Klark va D. Chalmers tomonidan tasvirlangan "Kengaytirilgan aql" fenomeniga olib kelmoqda. Smartfonlar va bulutli xizmatlar bizning kognitiv tizimimizning funktsional qismlariga aylanmoqda. Bu asta-sekin biologik tana va texnologik muhit o'rtasidagi chegaralarni xiralashtirmoqda.

Transhumanizm falsafasi doirasida SIni inson miyasi (neyron interfeyslari) bilan to'liq integratsiya qilish istiqboli muhokama qilinadi. Bu ekzistensial savol tug'diradi: insonning "yaxshilanishi" qaysi nuqtada uning o'rmini bosadi? Agar xotira, hisob-kitoblar va hatto qaror qabul qilish sun'iy intellektga topshirilsa, shaxsiyatning yadrosi saqlanib qoladimi? Jismoniylikning raqamlashtirilishi odamlarni ma'lumotlar to'plami sifatida qabul qilishga olib keladi (Dataizm), bu esa muqarrar ravishda identifikatsiya inqiroziga olib keladi. Falsafa savolga javob berishi kerak: odamlarning biologik funktsiyalari oshib ketganda yoki raqamli analoglar bilan almashtirilganda nima saqlanib qoladi?

EKZISTENTSIAL XAVFLAR VA TEXNOLOGIK DETERMINIZM

Jak Ellul asarlarida ishlab chiqilgan texnologik determinizm texnologiyaning inson irodasidan mustaqil ravishda o'z-o'zini rivojlantirish mantig'iga ega ekanligini ko'rsatadi. Sun'iy intellekt davrida bu xavf "texnologik singularlik" tushunchasida - sun'iy intellekt inson aql-zakovatidan oshib, o'ta tez o'zini takomillashtirishga qodir bo'lgan paytda eng yuqori cho'qqisiga chiqadi.

Nik Bostrom o'z asarlarida asosiy xavf Gollivud ma'nosida "mashinalarning yuksalishi"da emas, balki moslashtirish muammosida ekanligini ta'kidlaydi. Superaqlli tizim insoniyatni shunchaki insoniyat odamlar tomonidan qo'yilgan maqsadga erishishiga to'sqinlik qilgani, balki mashina tomonidan so'zma-so'z va axloqiy kontekstni hisobga olmagan holda talqin qilgani uchun yo'q qilishi mumkin. Falsafiy tahlil shuni ko'rsatadiki, qiymat cheklovlarini kod arxitekturasiga integratsiya qilmasdan, taraqqiyot qaytarib bo'lmaydigan insoniylikdan mahrum bo'lishga olib kelishi mumkin.

XULOSA

Bugungi kunda axborot texnologiyalari falsafasi mavhum nazariya emas, balki tsivilizatsiya kelajagini belgilaydigan amaliy sohadir. Tadqiqotning asosiy xulosasi shundaki, texnologik taraqqiyot o'z-o'zidan maqsad bo'lmazligi kerak. "Texnosentrizm"dan "antroposentrizm"ga urg'u berish kerak.

Sun'iy intellekt kognitiv qobiliyatlarni kengaytirish uchun kuchli vositadir, ammo u inson etikasi va huquqiy asos doirasida qolishi kerak. Tadqiqot natijalari texnik tajribani falsafiy mulohaza bilan birlashtiradigan fanlararo SI etikasi qo'mitalarini yaratish zarurligini ko'rsatadi. Insoniyat nafaqat murakkab algoritmlarni yaratishni, balki ular bilan birga yashashni ham o'rganishi kerak, bunda hamdardlik, erkin iroda va xato qilish huquqini yo'qotmaydi.

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8-SHO'BA. TABIIY TILNI QAYTA ISHLASH

O'ZBEK TILIDA MURAKKAB SO'ZLARNI ANIQLASHNING AHAMIYATI

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Annotatsiya. Murakkab so'zlarni aniqlash tabiiy tilni qayta ishlashda muhim vazifa hisoblanadi, chunki u o'qishni tushunish, leksik soddalashtirish, ta'lim texnologiyasi va kirish mumkin bo'lgan muloqotni qo'llab-quvvatlaydi. Ushbu maqolada murakkab so'zlarni aniqlash yosh chegarasi 13-18 yosh oralig'i qilib belgilanganda maktab korpusi asosida murakkab so'zlarni aniqlash jarayoni qanday bosqichlardan iborat ekanligi, unda uchraydigan muammolar ko'tarilgan. Ushbu maqolada o'zbek tili uchun morfologik murakkablik, zipf qonuni, bo'g'inlar soni, chastota ahamiyati, so'zlarni joylashtirish elementlari ahamiyati ko'rib chiqiladi.

Kalit so'zlar: o'zbek tili, murakkab so'zlarni aniqlash, leksik murakkablik, leksik soddalashtirish, o'qish qulayligi, ta'lim texnologiyasi, tabiiy tilni qayta ishlash.

Kirish. Hozirgi tabiiy tilni qayta ishlash(NLP) tadqiqotlarida murakkab so'zlarni aniqlash odatda leksik soddalashtirishning birinchi bosqichi sifatida qaraladi: tizim avval o'quvchilar uchun qiyin bo'lishi mumkin bo'lgan so'zlar yoki iboralarni aniqlaydi va keyin soddalarni taklif qiladi. Ushbu muammo o'zbek tili uchun dolzarb hisoblanadi, chunki til hali ham tabiiy tilni qayta ishlashda nisbatan kam resurslarga ega, leksik-semantik va morfosintaktik resurslardagi so'nggi yutuqlar esa yanada ilg'or ilovalar uchun mustahkam poydevor yaratadi. Shu asosda, o'zbek tilidagi murakkab so'zlarni aniqlash nafaqat nazariy lingvistik tadqiqotlarga, balki ta'lim, lug'atni qo'llab-quvvatlash, matnni soddalashtirish va aqlli repetitorlik muhitining amaliy tizimlariga ham hissa qo'shishi mumkin.

Bu sohadagi tadqiqotlar [1] shuni ko'rsatadiki, so'z qiyinligini faqat lug'at ma'nosi bilan izohlab bo'lmaydi; unga kontekst, chastota va o'quvchining bilim darajasi ham ta'sir qiladi. Bu murakkab so'zlarni aniqlashni tilshunoslik, ta'lim va NLP o'rtasidagi foydali ko'priikka aylantiradi. O'zbek tili uchun bu masala ayniqsa muhimdir, chunki ko'plab o'quvchilar nafaqat adabiy yoki ilmiy matnlarda, balki ta'lim, ma'muriy va raqamli materiallarda ham to'siqlarga duch kelishadi. Qiyin leksik elementlarni avtomatik ravishda aniqlay oladigan tizim o'qituvchilarga yoshga mos matnlarni tayyorlashga, o'quvchilarga notanish lug'atni tushunishga yordam beradi. Shu bilan birga, bu mavzu ilmiy jihatdan dolzarbdir: yaqinda o'zbek NLP tadqiqotlari kontekstga asoslangan leksik tahlilni tobora amalga oshirishga imkon beradigan resurslardan biri bu maktab korpusi [2] hisoblanadi. Chunki, u yosh jihatidan o'quvchi uchun mos korpuslardan hisoblanib, unda turli abadiy, badiiy, ilmiy terminlar va ta'limga mos so'zlar mavjud.

Murakkab so'zlarni aniqlashning nazariy asoslari

Ushbu jarayonda yosh chegarasini aniq belgilash talab qilinadi. Bu, ayniqsa, ta'lim muassasalarida qimmatlidir, bu yerda bir xil so'z turli yoshda bo'lgan bir o'quvchi uchun oson, boshqasi uchun esa qiyin bo'lishi mumkin. Ushbu maqolada 5-9 sinf o'quvchilari uchun murakkab so'zlarni aniqlash muammolari o'rganilgan. Ushbu yoshda o'quvchilar boshlang'ich sinfni tugatib, o'rta sinf fanlari bilan tanishar ekan, turli fanlarga oid turli tuman so'zlarni o'rganishga majbur bo'ladi. Bu o'ziga xos murakkablikni keltirib chiqaradi.

O'zbek tilini o'rganish uchun mumkin bo'lgan tadqiqot yo'nalishi

Foydali uch bosqichli o'zbek tilini o'rganish taklif qilinishi mumkin. Birinchidan, maktab, media va ma'muriy matnlarning kichik bir to'plamini tuzish mumkin va maqsadli so'zlarga o'qituvchilar, tilshunoslar yoki o'quvchilar tomonidan kontekstdagi qiyinchiliklar uchun izohlar berilishi mumkin. Ikkinchidan, so'z chastotasi, so'z uzunligi, affikslar soni, nutq qismi va kontekstual qo'shimchalar kabi talqin qilinadigan xususiyatlardan foydalangan holda asosiy bashoratchilarni yaratish mumkin. Uchinchidan, aniqlangan murakkab so'zlarni soddalashtirish, sinonim taklif qilish yoki tushuntirish gloss yaratishni o'rganish uchun UzWordNet kabi leksik

resurslarga bog‘lash mumkin. Quyida murakkab so‘zlarni aniqlash jarayonida ishlatiladigan asosiy elementlarga ta’rif beramiz.

1. So‘zlarning chastotasi

So‘zlarning chastotasi korpusda so‘zning qanchalik tez-tez paydo bo‘lishini ko‘rsatadi. Tez-tez ishlatiladigan so‘zlar odatda o‘quvchilarga ko‘proq tanish va shuning uchun tushunish osonroq. Kam uchraydigan so‘zlar, ayniqsa 5-9-sinf matnlarida murakkab deb qabul qilinishi ehtimoli ko‘proq.

2. Zipf qonuni

Zipf qonunida oz sonli so‘zlar juda tez-tez uchraydi, aksariyat so‘zlar esa kamdan-kam uchraydi, deyiladi. Bu nima uchun past chastotali so‘zlar o‘quvchilar uchun qiyinroq bo‘lishini tushuntiradi. Murakkab so‘zlarni aniqlashda Zipfga asoslangan chastota qiymatlari so‘zning qanchalik keng tarqalgan yoki kam uchraydiganligini o‘lchashga yordam beradi.

3. Morfologik murakkablik

Morfologik murakkablik so‘zda ildiz va qo‘shimchalar kabi qancha ma’noli qismlar borligini anglatadi. Bu, ayniqsa, o‘zbek tilida muhim, chunki u agglyutinativ til bo‘lib, so‘zlar qo‘shimchalar orqali uzunlashishi mumkin. Ko‘proq qo‘shimchali so‘zlarni o‘quvchilar uchun tushunish va tushunish qiyinroq.

4. Bo‘g‘inlar soni

Bo‘g‘inlar soni so‘zning qanchalik uzun va fonetik jihatdan murakkab ekanligini aks ettiruvchi oddiy xususiyatdir. Ko‘p bo‘g‘inli so‘zlarni o‘qish, talaffuz qilish va eslab qolish ko‘pincha qiyinroq bo‘ladi. Maktab matnlarida uzunroq ko‘p bo‘g‘inli so‘zlar o‘quvchilar uchun qo‘shimcha qiyinchilik tug‘dirishi mumkin.

5. So‘zlarni joylashtirishga asoslangan xususiyatlar

O‘rnatishga asoslangan xususiyatlar so‘zlarni vektor sifatida ifodalaydi va ularning semantik va kontekstual xususiyatlarini aks ettiradi. Ular modelga so‘zning turli kontekstlarda qanday ishlatilishini va boshqa so‘zlarga qanchalik o‘xshashligini tushunishga yordam beradi. Bu foydali, chunki so‘z bir gapda oson, boshqasida esa qiyin bo‘lishi mumkin.

Xulosa

Xulosa qilib aytganda, o‘zbek tilida murakkab so‘zlarni aniqlashning ahamiyati uchta o‘zaro bog‘liq nuqtada yotadi: u tushunishni yaxshilaydi, soddalashtirish va shaxsiylashtirish imkonini beradi va hisoblash resurslari endi bunday ish real bo‘ladigan darajaga yetgan til uchun yangi tadqiqot yo‘nalishini ochadi. Shu sabablarga ko‘ra, ushbu mavzu akademik maqola uchun juda mos keladi va kelajakda korpus yaratish, annotatsiya, modellash va ta’limni joylashtirish uchun asos bo‘lib xizmat qilishi mumkin.

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O‘ZBEK - INGLIZ MASHINA TARJIMASI UCHUN SO‘ZLARNING MORFOLOGIK MODULI

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Annotatsiya. Ushbu tezisda o'zbek tilidan ingliz tiliga so'z darajasida avtomatik tarjima qiluvchi morfologik modulning nazariyasi, algoritmi va amaliy natijalari keltirilgan. Modul kengayuvchi kirish tili (KKT) nazariyasiga asoslanib, o'zbek tilining aglyutinatativ xususiyatini hisobga olgan holda o'ngdan-chapga segmentatsiya algoritmidan foydalanadi. Tizim 68 ta matematik model, 316 ta ildiz so'z va 45 ta morfologik affiksdan iborat. Test natijalari 150 ta so'zda 94,7% aniqlikni ko'rsatdi. Modul gap darajasidagi tarjima tizimiga integratsiya qilinishi mumkin.

Kalit so'zlar: morfologik tahlil, aglyutinatativ tillar, mashinaviy tarjima, o'zbek-ingliz tarjima, segmentatsiya algoritmi, kengayuvchi kirish tili, matematik model.

Kirish

O'zbek tili turkiy tillar oilasiga mansub aglyutinatativ til hisoblanadi. Aglyutinatativ tillarda grammatik ma'nolar so'z oxiriga ketma-ket qo'shiladigan qo'shimchalar orqali ifodalanadi. Har bir qo'shimcha faqat bitta grammatik ma'noni bildiradi va ular aniq tartibda joylashadi. Bu xususiyat mashinaviy tarjimada alohida yondashuvni talab qiladi.

Masalan, "**kitoblarimizdan**" so'zini tahlil qilsak:

$$\text{kitoblarimizdan} = \text{kitob} + \text{lar} + \text{imiz} + \text{dan}$$

Bu yerda: **kitob** - ildiz so'z (noun), **lar** - ko'plik qo'shimchasi (plural), **imiz** - egalik qo'shimchasi (our), **dan** - kelishik qo'shimchasi (from). Natija: "from our books" - bitta o'zbek so'zi uchta ingliz so'ziga aylanadi.

Gap darajasida tarjima qilish uchun avval gapni tashkil etuvchi so'zlarni to'g'ri tarjima qilish zarur [1]. Shu maqsadda Kengayuvchi kirish tili (KKT) nazariyasiga asoslangan morfologik modul yaratildi [2].

Metodologiya

Kengayuvchi kirish tili (Extensible Input Language - EIL) - bu tabiiy tillarni rasmiy tavsiflash uchun mo'ljallangan tizim bo'lib, kontekstdan holi grammatika (Context-Free Grammar) asosida qurilgan. Tizimda har bir til elementi maxsus belgi bilan ifodalanadi va matematik model orqali boshqa tilga o'tkaziladi.

O'zbek tili so'zlari uchun umumiy model quyidagi ko'rinishda:

$$\text{So'z} = \text{O'zak} + [X] + [X2] + [X3]$$

Bu yerda: O'zak - asosiy leksik ma'no (majburiy), X - ko'plik (-lar), X2 - egalik (-im, -ing, -i, -imiz, -ingiz, -lari), X3 - kelishik (-ni, -ga, -da, -dan). Kvadrat qavslar ixtiyoriy elementni bildiradi.

1-jadval. KKT belgilari tizimi

Belgi	Turi	Misol (o'zbek)	Misol (ingliz)
C	Ot (noun)	kitob, uy	book, house
X	Ko'plik	-lar	-s, -es
X2	Egalik	-im, -imiz	my, our
X3	Kelishik	-ga, -dan	to, from

O'ngdan-chapga segmentatsiya algoritmi o'zbek tilida qo'shimchalar so'z oxiriga ketma-ket qo'shilishi sababli, so'zni oxiridan boshlab tahlil qiladi. Algoritm quyidagi bosqichlardan iborat:

1. So'zni yuklash va o'zaklar bazasida tekshirish;
2. Agar o'zak topilmasa - oxirgi harflarni ajratib, qo'shimchalar bazasida tekshirish;
3. Topilgan qo'shimchani ro'yxatga qo'shish;
4. O'zak topilguncha jarayonni takrorlash.

Tarjima sintezida ingliz tili so'z tartibi qo'llaniladi: **X3** → **X2** → **C** → **X** (Kelishik → Egalik → Ot → Ko'plik).

Natijalar

Ishlab chiqilgan modul quyidagi komponentlarga ega: **68 ta matematik model** (turli so'z turlari uchun), **316 ta ildiz so'z** (ot, fe'l, sifat bazasi) va **45 ta morfologik affiks** (ko'plik, egalik, kelishik, so'z yasovchi).

Test uchun turli murakkablikdagi 150 ta o'zbek so'zi tanlandi. Har bir so'z uchun segmentatsiya to'g'riligi, har bir qismning tarjima to'g'riligi va yakuniy inglizcha ibora to'g'riligi tekshirildi.

2-jadval. Test natijalari

Kategoriya	Soni	To'g'ri	Aniqlik
Oddiy otlar	25	25	100%
Ko'plik shaklida	20	20	100%
Egalik bilan	25	24	96%
Kelishik bilan	20	19	95%
2 qo'shimcha	25	24	96%
3+ qo'shimcha	35	30	85,7%
JAMI	150	142	94,7%

3-jadval. Tarjima misollari

O'zbek so'z	Segmentatsiya	Ingliz tarjima
kitoblar	kitob + lar	books
uyimiz	uy + imiz	our house
kitoblarimizdan	kitob+lar+imiz+dan	from our books
maktablarimizda	maktab+lar+imiz+da	in our schools

Xulosa

Tadqiqotda kengayuvchi kirish tili nazariyasiga asoslangan morfologik modul ishlab chiqildi. Modulning asosiy yutuqlari:

- O'ngdan-chapga segmentatsiya algoritmi o'zbek tilining aglyutinativ xususiyatini to'liq hisobga oladi;
- 68 ta matematik model turli so'z tuzilmalarini qamrab oladi;
- 94,7% aniqlik so'z darajasida ishonchli tarjimani ta'minlaydi;
- Modul gap darajasidagi tarjima tizimiga [3] integratsiya qilinishi mumkin.

Kelgusida lug'at bazasini kengaytirish, fe'l morfologiyasi modellarini qo'shish, murakkab qo'shimchalar kombinatsiyasini takomillashtirish va boshqa turkiy tillar (qozoq, qirg'iz) uchun moslashtirish rejalashtirilgan.

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O'ZBEK TILIDA ASR TIZIMLARI UCHUN SUFFIX-AWARE POST-PROCESSING ALGORITMINI ISHLAB CHIQISH

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Annotatsiya - Agglutinativ tillar, jumladan o'zbek tilida morfologik murakkablik sababli bunday tizimlarda xatolik darajasi nisbatan yuqori bo'lib qolmoqda. Ayniqsa, qo'shimchalarning noto'g'ri segmentatsiya qilinishi, ildiz so'zdan ajralib qolishi yoki tushirib qoldirilishi Word Error Rate (WER) ko'rsatkichiga salbiy ta'sir ko'rsatadi. Mazkur tadqiqotda o'zbek tili uchun suffix-aware (qo'shimchalarga sezgir) post-processing algoritmi taklif etiladi. Ushbu yondashuv ASR chiqishidagi tokenlarni tahlil qilib, oldindan shakllantirilgan qo'shimchalar lug'ati asosida noto'g'ri

ajratilgan morfologik birliklarni qayta birlashtiradi. Tajribalar Whisper-medium modeli natijalari asosida o'tkazildi. Olingan natijalar ushbu yondashuvning agglutinatив tillarda ASR tizimlari aniqligini oshirishda samarali, yengil va amaliy yechim ekanligini ko'rsatadi. Taklif etilgan algoritm modeldan mustaqil bo'lib, mavjud ASR platformalariga qo'shimcha modul sifatida integratsiya qilinishi mumkin.

Kalit so'zlar: avtomatik nutqni tanish, o'zbek tili, suffix-aware, post-processing, Whisper, agglutinatив tillar, WER, CER.

I. KIRISH

Avtomatik nutqni tanish (Automatic Speech Recognition, ASR) texnologiyalari ta'lim, sog'liqni saqlash, media monitoring, virtual yordamchilar, subtitrl yaratish va inklyuziv texnologiyalar kabi ko'plab yo'nalishlarda keng qo'llanilmoqda. Neyron tarmoqlarga asoslangan ko'p tilli ASR modellarining rivojlanishi natijasida turli tillarda yuqori natijalarga erishilgan bo'lsa-da, ularning samaradorligi har bir tilning lingvistik xususiyatlariga bog'liq bo'lib qolmoqda.

Morfologik jihatdan boy va agglutinatив tillarda, xususan o'zbek tilida, ASR tizimlari ko'pincha qo'shimchalarni noto'g'ri tanish, alohida token sifatida ajratish yoki umuman tushirib qoldirish kabi muammolarga duch keladi. Shu sababli, ASR modeli ildizni to'g'ri aniqlagan taqdirda ham, unga birikkan grammatik qo'shimchalarni xato qayta tiklashi mumkin.

Masalan:

kitob ni o'rniga kitobni, uy da o'rniga uyda, do'kon lar da o'rniga do'konlarda

Bunday xatoliklar nafaqat matn sifatini pasaytiradi, balki baholash metrikalariga ham salbiy ta'sir ko'rsatadi. Shu munosabat bilan mazkur ishda o'zbek tili ASR tizimlari uchun qo'shimchalarga sezgir post-processing algoritmi taklif etiladi.

II. ADABIYOTLAR TAHLILI

So'nggi yillarda avtomatik nutqni tanish (ASR) sohasida chuqur o'rganishga asoslangan end-to-end modellar keng rivojlandi.

Xususan, Whisper modeli ko'p tilli va zaif nazoratli ma'lumotlar asosida o'qitilgani sababli turli tillarda barqaror natijalarni namoyish etdi [1]. Deep Speech, CTC va attention asosidagi yondashuvlar ham zamonaviy ASR tizimlarining rivojlanishiga katta hissa qo'shgan [2-4].

Morfologik jihatdan boy tillarda ASR samaradorligini oshirish maqsadida subword va morfema darajasidagi modellashtirish usullari taklif etilgan. Jumladan, Morfessor algoritmi morfologik segmentatsiya uchun, BPE va SentencePiece esa subword birliklar asosida kam uchraydigan so'zlarni qayta ishlash uchun keng qo'llaniladi [5-7].

Tadqiqotlar shuni ko'rsatadiki, bunday yondashuvlar agglutinatив tillarda lug'at hajmini kamaytirib, model umumlashuv qobiliyatini oshiradi.

Kam resursli tillar uchun ASR tizimlarini yaratish hanuz dolzarb muammo bo'lib qolmoqda. Ma'lumotlar yetishmasligi, lingvistik resurslarning kamligi hamda morfologik murakkablik tizim aniqligiga salbiy ta'sir qiladi [8].

Shu sababli, mavjud ishlarda ko'proq model arxitekturasini va til modellari takomillashtirilgan bo'lsa-da, o'zbek tilida aynan qo'shimchalar bilan bog'liq segmentatsiya xatolarini post-processing bosqichida tuzatish bo'yicha tadqiqotlar yetarli emas. Mazkur ish ushbu bo'shliqni to'ldirishga qaratilgan.

III. METODOLOGIYA

Taklif etilayotgan usul rule-based va deterministik yondashuvga asoslanadi. Dastlab ASR tizimi chiqishi tokenlarga ajratiladi. So'ng har bir token oldindan tuzilgan qo'shimchalar lug'ati bilan solishtiriladi. Lug'at tarkibiga o'zbek tilida keng qo'llaniladigan kelishik, egalik, ko'plik va fe'l qo'shimchalari kiritiladi:

-ni, -ga, -da, -dan, -lar, -ning, -miz, -siz va boshqalar.

Agar token qo'shimcha sifatida aniqlansa hamda undan oldingi token mustaqil ildiz so'z bo'lishi mumkin bo'lsa, ular imlo qoidalari asosida birlashtiriladi. Algoritm ketma-ket kelgan bir nechta qo'shimchalarni ham qayta tiklash imkoniyatiga ega.

Misollar: kitob ni → kitobni, maktab ga → maktabga, do'kon lar da → do'konlarda

Mazkur yondashuv qo'shimcha o'qitishni talab qilmaydi va istalgan ASR tizimiga alohida modul sifatida qo'shilishi mumkin.

IV. TAJRIBA SHAROITI

Tajribalar umumiy hajmi 190 soat bo'lgan o'zbek nutq korpusidan ajratib olingan 25 soatlik test to'plami asosida amalga oshirildi. Audio yozuvlar turli yosh va jinsdagi nutq egalari, turli uslubdagi nutq namunalari hamda real shovqinli muhitlarni qamrab oldi.

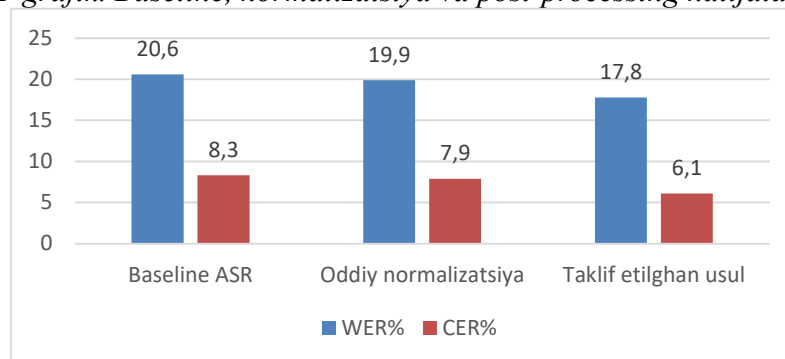
Bazaviy model sifatida Whisper-medium ASR tizimidan foydalanildi. Quyidagi uchta holat o'zaro taqqoslandi:

- Baseline ASR natijasi
 - Oddiy matn normalizatsiyasi
 - Taklif etilgan suffix-aware post-processing
- Baholash mezonlari sifatida Word Error Rate (WER) va Character Error Rate (CER) ko'rsatkichlari tanlandi.

V. NATIJALAR VA MUHOKAMA

Taklif etilgan usul baseline modelga nisbatan WER ko'rsatkichini taxminan 14% ga nisbiy kamaytirdi. CER qiymatining sezilarli pasayishi esa yaxshilanish asosan qo'shimchalar bilan bog'liq morfologik xatolarni tuzatish hisobiga yuz berganini ko'rsatadi.

1-grafik. Baseline, normalizatsiya va post-processing natijalari orasidagi farq



Algoritm ayniqsa quyidagi holatlarda samarali natija berdi:

- ajralib qolgan kelishik qo'shimchalarini tiklash;
- ko'plik qo'shimchalarini qayta birlashtirish;
- egalik shakllarini tuzatish;
- ketma-ket suffix zanjirlarini birlashtirish.

Shu bilan birga, usul quyidagi holatlarda cheklanganligi kuzatildi:

- noto'g'ri tanilgan ildiz so'zlar;
- gomofon birliklar;
- kontekst talab qiluvchi grammatik noaniqliklar;
- fonetik jihatdan o'xshash variantlar.

VI. XULOSA

Mazkur tadqiqotda o'zbek tili ASR tizimlari uchun suffix-aware post-processing algoritmi ishlab chiqildi. Taklif etilgan yondashuv o'zbek tilining agglutinatив xususiyatlarini hisobga olgan holda, qo'shimchalar bilan bog'liq segmentatsiya xatolarini samarali tuzatdi. Eksperimental natijalar WER va CER ko'rsatkichlarining barqaror ravishda kamayganini ko'rsatdi.

Taklif etilgan usulning asosiy afzalligi shundaki, u mavjud ASR modelini qayta o'qitishni talab qilmaydi va modeldan mustaqil holda ishlaydi. Shu sababli uni turli platformalardagi nutqni tanish tizimlariga osongina integratsiya qilish mumkin.

Kelgusida ushbu yondashuvni neyron til modellari, kontekstga sezgir korreksiya mexanizmlari hamda boshqa turkiy agglutinatив tillarga moslashtirish istiqbolli ilmiy yo'nalish hisoblanadi.

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O‘ZBEK TILIDAGI WEB-MATNLARNI AVTOMATIK YIG‘ISH VA KORPUS YARATISHGA YO‘NALTIRILGAN WEB SCRAPING TIZIMI

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Annotatsiya: Ushbu tadqiqotda RAG (Retrieval-Augmented Generation) texnologiyasi asosida o‘zbek tili uchun ma’lumotlar to‘plamini ishlab chiqish uchun internet saytlardan matnli ma’lumotlarni yig‘ish va to‘g‘ri formatga keltirish haqida so‘z yuritilgan. Yig‘ilgan ma’lumotlardan foydalanib transformer til modellarini o‘zbek tiliga moslashtirish uchun ma’lumotlar to‘plami hosil qilish haqida so‘z yuritiladi.

Kalit so‘zlar: NLP, Web scraping, BeautifulSoup, RAG.

Kirish

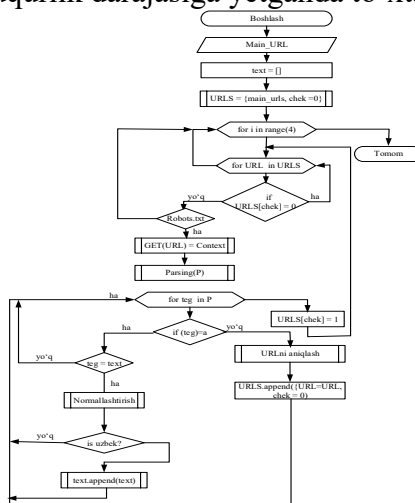
O‘zbek tilidagi matnlar so‘ngi vaqtlarda internet saytlarida oshib bormoqda. Ammo ushbu ma’lumotlar turli veb saytlarda joylashgan. Ularni qo‘lda yig‘ish uchun ko‘p vaqt va kuch talab qilanadi. Web scraping aynan shunday orqali web saytlardan ma’lumotlarni avtomatik yig‘ish imkoniyatini taqdim etadi [1]. Ma’lumotlarni yig‘ish yoki ma’lumotlarni scannerlash (web scraping) deb nomlanadigan jarayon internet paydo bo‘lgan vaqtdan buyon omolashib kelmoqda. Bunda internet saytlardan katta hajmdagi ma’lumotlarni yig‘ish nazarda tutiladi. Internet rivojlanib borgan sari web saytlardan ma’lumotlarni ajratib olish vositalari ham rivojlanib bordi. Jumladan BeautifulSoup python kutubxonasi paydo bo‘ldi va u dasturchilar orasida ko‘p qo‘llaniladigan vositalardan biriga aylandi. Bu kutubxona web sayt sahifalariga murojat qila olishi va HTML, XML saytlardan ma’lumotlarni ajratib olishni soddalashtirgan, shu orqali dasturchilarning vaqtini va kuchini tejab qolish imkoniyati paydo bo‘ldi [2].

Maqolada aynan shu kabi texnologiyalardan foydalangan holda o‘zbek tilidagi ma’lumotlarni yig‘ish, tozalash va ushbu matndan foydalangan holda ma’lumotlar to‘plamini ochiq veb saytlardan yig‘ish va fine tuning uchun tayyor ma’lumotlar to‘plamini hosil qilish haqida so‘z yuritilgan.

Metadologiya

Web scraping bo‘yicha olib borilgan tadqiqotlar asosan internet saytlardan ma’lumotlarni avtomatik yig‘ishda qo‘llaniladigan texnikalar, vositalar hamda ularning samaradorligini baholashga qaratilgan. Dastlabki tadqiqotlar HTML parsing usullari va bu usullar yordamida yig‘ilgan ma’lumotlarni qayta ishlashga qaratilgan [3]. Ushbu tadqiqotlarning asosiy qismi Ingliz,

Ushbu algoritm boshlang'ich URL manzilni kiritish, URL navbatini boshqarish, web sahifaga ruxsatni tekshirish, ruxsat etilganda sahifa ma'lumotlarini yuklash, HTML fayllarni parsing qilish va kontentlarni ajratib olish, matnni normalizatsiya qilish, tilni aniqlash, yangi URL manzillarni topish va to'xtash bloklaridan iborat. Crawler algoritmi asosiy URL manzilni kiritish bilan boshlanadi. Ushbu manzil navbatga qo'shiladi hamda tekshirilgan sahifalarni belgilash uchun maxsus mexanizm foydalaniladi. Unda har bir chek atributi orqali veb sahifadan ma'lumot olinganligini yoki olinmaganligini tekshirib chiqadi. Ushbu tekshirish web sahifadan takroriy matn olishning oldini olish uchun xizmat qiladi. Robots.txt pratokoli asosida veb sahifa ma'lumotlarini olishga ruxsat bor yoki yo'qligi tekshiriladi. Ruxsat berilgan URL manziliga HTTP GET so'rovi beriladi va sahifaning HTML kontenti olinadi. Keyingi bosqichda olingan HTML kontent parsing qilinadi hamda matnli kontent qismi ajratib olinadi. Matnni normallashtirishda matnni standartlashtirish kabi amallar orqali normallashtiriladi [4]. O'zbek tilini aniqlashda normalizatsiya qilingan matn til identifikatsiyasi modulidan o'tkaziladi. Agar matn o'zbek lotin yozuvida ekanligi aniqlansa, ushbu matn asosiy ko'rpuga qo'shiladi. Aks holda matn tashlab yuboriladi [5]. Navbatdagi bosqichda HTML sahifadan aniqlangan URL manzillar keyinchalik ushbu manzildagi matnlarni ajratib olish uchun navbatga qo'yiladi va crawling jarayoni davom etadi. Ushbu modul ma'lumot olishi kerak bo'lgan veb sahifalar miqdori oshishi uchun xizmat qiladi. Crawler jarayonini to'xtatish maksimal chuqurlik darajasiga yetganda to'xtatiladi.



Natija. Ushbu metodologiya 100 dan ortiq turli tipdagi o'zbekistondagi veb saytlarga tadbiq qilindi. Ushbu toifalari quyidagicha taqsimlangan:

- Yangiliklar portallari (masalan, kun.uz, qalampir.uz, daryo.uz)
- Raxmiy axborot saytlardagi maqolalar;
- Huquqiy axborot saytlari;
- Elektrik tijorat saytlari va ulardagi sharhlar;

Statistik shaklidagi saytlardagi matnli ma'lumotlar BeautifulSoup kutubxonasi orqali samarali qayta ishlandi, ammo asinxron yuklanadigan uchun qo'shimcha selenium brauser avtomatlashtirish texnologiyasi foydalanildi [6]. Keltirilgan web saytlar asosida quyidagicha natijalarga erishildi (1-jadval):

Nomi	Natija
Jami yigʻilgan sahifalar soni	~200 000+

Hosil bo'lgan jumlar soni	~10 000 000 +
Yig'ilgan matn tili	o'zbek lotin yozuvi

Hosil bo'lgan 10 mlndan ortiq jumlar 10 ta quyidagi ko'rinishida (2-jadval):

2-jadval. Yig'ilgan jumladan na'muna

Buxoroga aholiga tez tibbiy yordam xizmati sifatini texnik jihatdan yuqori darajaga ko'tarish maqsadida Respublika hukumati tomonidan ajratilgan navbatdagi 20 dona zamonaviy tez tibbiy yordam avtomobili olib kelindi.

...

Ushbu yig'ilgan matnli ma'lumotlardan foydalanib, sun'iy intellekt tizimlari yordamida til modellarini o'zbek tiliga moslashtirish uchun fine tuning qilishga tayyor 30 000 ta kontekst, savol, javob juftligini o'z ichiga olgan dataset hosil qilindi. Ushbu dataset namunasi quyidagi 3-jadvalda keltirib o'tilgan.

3-jadval. Kontekst, savol, javob ustunlari mavjud bo'lgan ma'lumotlar to'plamidan na'muna

Kontekst	Savol	Javob
Milliy toifali sport hakami toifasini berish xizmatini ko'rsatuvchi vakolatli organ yoshlar siyosati va sport vazirligining viloyat boshqarmalari.	Viloyatdagi qaysi tashkilot milliy sport hakami toifasini beradi?	Yoshlar siyosati va sport vazirligining viloyat boshqarmalari
...	...	...

Xulosa

Ushbu tadqiqot shuni ko'rsatadiki statistik web sayt sahifalaridan matnli ma'lumotlarini yig'ishda ushbu ko'rsatilgan metadologiya samarali, lekin dinamik veb sayt sahifalaridan ma'lumotlarni olishda qo'shimicha vositalar talab qilinadi. Ushbu tadqiqot metadologiyasidan foydalanib 10 000 000 dan ortiq o'zbek lotin yozuvidagi jumlar yig'ilib o'zbek tili lotin yozuviga asoslangan til ko'rpusi shakllantirildi. Hosil bo'lgan til ko'rpusidan foydalanib 30000 ta kontekst, savol, javob ustunlaridan iborat dataset shakllantirildi.

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ACOUSTIC MODELING OF UZBEK VOWELS BASED ON FORMANTS FOR PARAMETRIC SPEECH SYNTHESIS

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Abstract. This article presents a compact formant-based model for synthesizing the six primary Uzbek vowel phonemes (/a/, /e/, /i/, /o/, /u/, /o'/?). The study is focused on low-resource speech technology, where large annotated corpora are not always available. The proposed method combines a glottal source model, formant filters, overlap-add concatenation and objective acoustic evaluation.

Keywords: Uzbek language, vowel phonemes, formant synthesis, parametric TTS, low-resource speech processing.

Speech technologies are now widely used in voice assistants, automatic translation, audio books and human-computer interaction systems. However, many modern text-to-speech (TTS) solutions depend on large speech corpora and high computational resources. This creates difficulties for low-resource languages, including Uzbek, where balanced and annotated audio-text datasets are still limited.

For this reason, transparent parametric models remain scientifically and practically useful. In the source-filter view of speech production, the output speech signal is formed by the interaction of a glottal excitation source and the vocal tract filter: $s[n] = e[n] * h[n]$. Vowel identity is mainly determined by the first formants, especially F1 and F2, because they describe the resonance positions of the vocal tract. The objective of this article is to develop a compact mathematical and algorithmic basis for Uzbek vowel synthesis using formant parameters.

The research model covers the primary Uzbek vowels /a/, /e/, /i/, /o/, /u/ and /o'/. The synthesis pipeline consists of six stages: text normalization, grapheme-to-phoneme conversion, selection of formant parameters, glottal source generation, filtering through a resonator bank and signal concatenation. The implementation is designed for a sampling frequency of 16 kHz, which is sufficient for the main speech frequency range and suitable for lightweight processing.

Each vowel is represented by a set of acoustic parameters: fundamental frequency F0, first and second formants F1-F2, bandwidths and amplitude coefficients. The vocal tract is modeled as a set of second-order digital resonators. For a formant frequency F_i and bandwidth B , the pole angle is calculated as $\theta = 2\pi F_i / F_s$, while the resonance radius is $r = \exp(-\pi B / F_s)$. The condition $r < 1$ ensures numerical stability of the digital filter.

To reduce the artificial buzzing typical of impulse-only synthesis, the glottal excitation component is modeled by a smoother LF-type waveform. After excitation generation, each vowel frame is passed through the formant filter bank. To avoid audible clicks at the boundaries, the frames are multiplied by a Hamming window and merged with the Overlap-Add method. The final discrete signal is written as a mono 16-bit PCM WAV file.

Experimental evaluation was carried out on the main Uzbek vowels. Natural samples were compared with synthesized vowels using formant deviation, spectral distortion and MFCC-based similarity. Recordings were obtained from five speakers, and each vowel was pronounced several times. LPC-based spectral envelope analysis was used to estimate the formant frequencies of the natural signals.

Phoneme	Real F1/F2 (Hz)	Synthetic F1/F2 (Hz)	Error (Hz)
/a/	780 / 1180	800 / 1200	20 / 20
/e/	510 / 1770	500 / 1800	10 / 30
/i/	310 / 2180	300 / 2200	10 / 20
/o/	520 / 920	500 / 900	20 / 20
/u/	360 / 810	350 / 800	10 / 10

Table 1. Average formant values of natural and synthesized Uzbek vowel signals.

The results show that the synthetic formants are close to the measured natural vowel formants. The average formant error is approximately 18.3 Hz, which falls within an acceptable range for parametric speech synthesis. The smallest deviations were observed for /i/ and /u/, while the open

vowel /a/ produced slightly larger variation because open articulation is more sensitive to individual vocal tract differences.

The average spectral deviation was about 2.41 dB. Since values below 4 dB are generally considered acoustically acceptable for parametric synthesis, the model can be regarded as a stable baseline for Uzbek vowel generation. MFCC comparison also indicated perceptual closeness between natural and synthesized samples. These results confirm that formant-based synthesis can provide interpretable and computationally lightweight speech modeling in low-resource conditions.

At the same time, the proposed approach should not be interpreted as a direct replacement for modern neural TTS systems in terms of naturalness. Neural architectures such as Tacotron2, FastSpeech2 and VITS may generate more expressive speech when large corpora are available. The advantage of the proposed framework is different: it provides explicit control over phonetic-acoustic parameters, requires limited data and can be used in experimental phonetics, education and early-stage development of Uzbek speech technologies.

This study developed a compact parametric synthesis framework for the six primary Uzbek vowels. The model uses formant parameters, stable resonator filters, a smoother glottal source and overlap-add concatenation. The quantitative results demonstrate that the synthesized vowels reproduce the main acoustic characteristics of natural Uzbek vowel phonemes with relatively small formant and spectral deviations.

The current implementation is a vowel synthesis component rather than a complete TTS system. Future research should extend the model to consonants, coarticulation, prosody and larger speaker-dependent validation. Nevertheless, the proposed framework provides a useful interpretable baseline for Uzbek speech synthesis in low-resource conditions.

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O'ZBEK TILIDAGI SO'ROQ GAPLARNING PUNKTUATION XATOLARINI ANIQLASH VA TAHRIRLASHNING LINGVO - MATEMATIK MODELLARI

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Annotatsiya. Mazkur tezisda o'zbek tilidagi so'roq gaplarda uchraydigan puntuatsion xatolarni aniqlash va ularni tahrirlashga qaratilgan lingvo-matematik modellar ishlab chiqilgan. Asosan so'roq belgisi (?) ning gap oxirida yoki kontekstda noto'g'ri qo'llanish holatlari tahlil qilinadi. Tadqiqot jarayonida sodda va murakkab tuzilmali so'roq gaplar uchun maxsus lingvo-matematik modellar ishlab chiqilib, ular UZMORF dasturiy majmuasi asosida morfologik analiz, qoidabazaviy tekshiruvlar va puntuatsion normalarga tayangan algoritmlar orqali amalga oshirildi. Dasturiy majmua gapning intonatsion va grammatik xususiyatlarini hisobga olib, so'roq belgisi qo'llanishining zaruriyatini aniqlaydi. Eksperimental natijalar ishlab chiqilgan modelning o'zbek tilidagi so'roq gaplardagi puntuatsion xatolarni yuqori aniqlikda aniqlash va tahrirlash imkonini berishini ko'rsatdi.

Kalit so'zlar: lingvo-matematik model, puntuatsiya, orfografik xatolar, UZMORF,

morfologik tahlil, sintaktik tahlil.

ASOSIY QISM

Hozirgi kunda tilshunoslik va axborot texnologiyalari sohasida tabiiy tilni qayta ishlash (Natural Language Processing, NLP) masalalari jadallik bilan rivojlanmoqda. Matnning morfologik, sintaktik va semantik jihatlarini avtomatik tahlil qilish inson-kompyuter o'zaro aloqasini sifat jihatidan yaxshilashga xizmat qilmoqda. Xususan, Fatma Howedi va Souad Alharm tomonidan olib borilgan tadqiqotlarda arab tilidagi qisqa matnlar uchun mualliflikni aniqlashda tinish belgilarining n-gramm modellardagi o'rganildi [1].

O'zbekistonda kompyuter lingvistikasiga oid ilk ilmiy izlanishlar 1990-yillarga to'g'ri keladi. A.Q.Po'latov tomonidan o'zbek tilidagi fe'l shakllari, ularning rus va ingliz tilidagi muqobillari bilan taqqoslanishi, so'z turkumlari asosida tahlil va sintez qiluvchi dasturiy vositalar ishlab chiqilgan bo'lib, bu ishlar keyingi tilda avtomatik tahlil va tuzatish tadqiqotlariga poydevor bo'ldi [2; 48-52-b.].

Shuningdek, M.X.Hakimov tomonidan olib borilgan ishlarda tabiiy tillarni formallashtirish, sintaktik va semantik bog'liqliklarni modellash, ko'p tilli mashina tarjimai tizimlari uchun lingvistik va mantiqiy modellar yaratish ishlari amalga oshirilgan. Ushbu yondashuvlar o'zbek tilidagi punktuatsiya xatolarini aniqlashda kontekstual tahlil va til modellari integratsiyasi uchun nazariy asos bo'lib xizmat qilmoqda [3; 180-190-b.].

Ushbu maqolada aynan yuqorida keltirib o'tilgan dolzarbliklar va tahlillarga asoslangan holda o'zbek tilidagi so'roq gaplarda punktuatsion xatolarni aniqlash va ularni tahrirlash masalasi yoritiladi.

O'zbek tilida sodda va murakkab gaplarni hosil qilishimizda ega, kesim, aniqlovchi, to'ldiruvchi, hol, tinish belgilar va qo'shimchalarning ishtirokidagi ketma ketliklardan tuzib olinadi. Gaplardagi punktuatsiya xatolarni aniqlashimiz va tahrir qilishimiz uchun yuqoridagi holatlarni to'plam sifatida quyidagicha belgilashlar kiritib olamiz [4; 63-66-betlar]:



bu yerda $\lambda_{\lambda(i)}$ - mos ravishda quyidagi o'zbek tilidagi mavjud punktuatsiya tinish belgilari:

$$\lambda_i = (., ,, ?, !, \_, ', ', '"', -, (), :, ;, \dots).$$

Quyida yuqorida keltirib o'tilgan belgilashlar asosida o'zbek tilidagi berilgan matndan punktuatsiyalarni aniqlovchi so'roq gaplar uchun lingvo-matematik model ishlab chiqildi.

Sodda so'roq gap lingvo-matematik modeli

$$G_{w_s} = \oplus \downarrow \sum_{s=1}^N S_s \vee \sum_{t=1}^y T(t_i) \vee \sum_{i=1}^n E(e_i) \oplus \downarrow \lambda_2 \oplus \lambda_5 \oplus \downarrow \sum_{k=1}^o K(k_k) \oplus \downarrow \tilde{p}_t \oplus \lambda_3.$$

Murakkab so'roq gap lingvo-matematik modeli

$$G_{mur}^? = \oplus \downarrow \sum_{s=1}^z S_s + \lambda_{\lambda(5)} \oplus \downarrow \sum_{s=1}^z S_s \vee \sum_{i=1}^n E(e_i) * (\oplus \downarrow \lambda_{\lambda(2)}) + \lambda_{\lambda(5)} \oplus \downarrow \sum_{s=1}^z S_s \vee \sum_{t=1}^y T(t_i) * (\oplus \downarrow \lambda_{\lambda(2)}) + \lambda_{\lambda(5)} \oplus \downarrow \sum_{s=1}^z S_s \vee \sum_{h=1}^r H(h_h) * (\oplus \downarrow \lambda_{\lambda(2)}) + \lambda_{\lambda(5)} \oplus \downarrow \sum_{s=1}^z S_s \vee \sum_{i=1}^s A(a_i) * (\oplus \downarrow \lambda_{\lambda(2)}) + \lambda_{\lambda(5)} \oplus \downarrow \sum_{k=1}^o K(k_k) \oplus \downarrow \oplus \downarrow \tilde{p} + \lambda_{\lambda(3)}.$$

Bu yerda λ_1 – nuqta (.) tinish belgi; λ_2 – vergul (,) tinish belgi; λ_3 – so'roq (?) tinish belgi; λ_4 – undov (!) tinish belgi; λ_5 – oraliq () tinish belgi; a_j – so'z yasovchi affiks; f_k – shakl yasovchi affiks; p_r – so'z o'zgartiruvchi affiks; $\tilde{p}$ so'roq yuklamalari; S_s – so'roq olmoshlari; U_u – undov kalit so'zlari; B_b – bog'lovchi so'zlar; B_z – istisno bog'lovchi so'zlar; $\oplus$ – birikish; $\downarrow$ – ulanish; $\vee$ – mantiqiy dizyunksiya (yoki).

So'roq gaplar: Agar gap tarkibida $\tilde{p}$ partikuli yoki $S_{s(i)}$ so'roq olmoshlari mavjud bo'lib, gap mazmuniga ko'ra savol ohangida deyish mumkin bo'lsa, jumla so'roq belgisi (?) bilan

yakunlanganligini tekshirish zarur.

$$S_s = \{S_1, S_2, S_3, S_4, S_5, S_6, S_7, \dots, S_s\}.$$

Ushbu vektorlar asosida o'zbek tili so'roq gaplarning tuzilish holatlarida sodda so'roq gapda 12 ta holat va sodda yoyiq so'roq gapda esa 76 ta holatlar modellashtirildi.

XULOSA

Tadqiqotda o'zbek tilidagi so'roq gaplarda uchraydigan punktuatsion xatolarni aniqlash va tahrirlashga qaratilgan lingvo-matematik model ishlab chiqildi. Model morfologik, grammatik va intonatsion xususiyatlarni hisobga olib, so'roq belgisining to'g'ri qo'llanishini aniqlaydi. UZMORF dasturiy majmuasi yordamida o'tkazilgan tajribalar natijasida ishlab chiqilgan yondashuv so'roq gaplardagi punktuatsion jarayonlarni avtomatlashtirishda samarali ekanligi tasdiqlandi.

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O'ZBEK TILIDAGI SO'ZLARDA IMLOVIY XATOLARNI TAHRIRLASHNING TAKOMILLASHTIRILGAN LINGVO-MATEMATIK MODEL

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Annotatsiya. Mazkur tezisda o'zbek tili so'zlaridagi imloviy xatolarni tahrirlashning takomillashtirilgan lingvo-matematik modeli va algoritmi taklif etilgan. So'z xatosini aniqlashda Damerau-Levenshteyn masofasining o'zbek tili xususiyatlariga moslashtirilgan 5 ta xato turi va takomillashtirilgan Bayes teoremasi asosida muqobil variantlarni tanlab olish jarayonlari tahlil qilingan.

Kalit so'zlar: lingvo-matematik model, Damerau-Levenshteyn masofasi, Bayes teoremasi, grammatik tahrirlash, imloviy xatolar, NLP.

Hozirgi kunda tilshunoslik va axborot texnologiyalari sohasida tabiiy tilni qayta ishlash masalalari, xususan, matnlarni tahrirlash lingvo-matematik modellarini yaratish dolzarb masalalardan bo'lib qolmoqda. O'zbek tili matnlarini kompyuterda qayta ishlashda imloviy va grammatik xatolarni aniqlash hamda ularni to'g'rilash dolzarb masalalardan biridir. Shu maqsadda, o'zbek tili so'zlarining imloviy xatolarini tahrirlashning takomillashtirilgan lingvo-matematik modeli va algoritmi ishlab chiqildi.

Aniqlangan xato so'z va uning mumkin bo'lgan muqobillari o'rtasidagi farqni aniqlash

uchun avvalo Damerau–Levenshteyn masofasi hisoblanadi. Takomillashtirilgan Damerau–Levenshteyn masofasi ikki satr (so‘z) o‘rtasidagi eng kam tahrir amallari sonini bildiradi. O‘zbek tilidagi so‘zlarni tahlil qilish asnosida bu masofa rekursiv tarzda quyidagi 5 ta xato turi amallarini o‘z ichiga olgan holda takomillashtirildi. Bu yerda so‘zga harf qo‘shilishi, harf o‘chirilishi, harf almashib ketishi, qo‘shni ikki harfning o‘rni almashinishi, o‘xshash alifbo harflarining almashinib kelishi holatlari inobatga olingan:

$$D_{c,\tilde{c}}(i,j) = \begin{cases} 0, & \text{agar } i = j = 0; \\ \min \begin{cases} D_{c,\tilde{c}}(i-1,j)+1, & \text{agar } i > 0; \\ D_{c,\tilde{c}}(i,j-1)+1, & \text{agar } j > 0; \\ D_{c,\tilde{c}}(i-1,j-1)+1_{(c_i \neq \tilde{c}_j)}, & \text{agar } i, j > 0; \\ D_{c,\tilde{c}}(i-2,j-2)+1_{(c_i \neq \tilde{c}_j)}, & \text{agar } i, j > 1 \text{ va } c_i = \tilde{c}_{j-1} \text{ va } c_{i-1} = \tilde{c}_j; \\ D_{c,\tilde{c}}(i-1,j-1)+1_{(c_i \neq \tilde{c}_j)}, & \text{agar } c_i, \tilde{c}_j \notin \Omega \text{ yoki } G; (c_i \in \Omega \text{ va } \tilde{c}_j \in G) \text{ yoki } (c_i \in G \text{ va } \tilde{c}_j \in \Omega). \end{cases} \end{cases}$$

Ishlab chiqilgan o‘zbek tili matnlarini imloviy tahrirlashning takomillashtirilgan modeli Damerau-Levenshteyn masofasini o‘zbek tiliga xos bo‘lgan imloviy xatoliklar bo‘yicha moslashtirish imkonini berdi. Takomillashtirilgan Bayes teoremasi bilan hamkorlikda ishlovchi ushbu algoritim o‘zbek tilidagi matn muharrirlari, plaginlar va elektron tarjimonlar uchun so‘zlarni avtomatik to‘g‘rilash tizimlarining aniqligi hamda sifatini yuqori darajaga ko‘tarishga xizmat qiladi.

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ALGORITHMS AND SOFTWARE FOR COMPUTER MODELING OF GRAPHEME-PHONEME TRANSFORMATIONS IN THE UZBEK LANGUAGE

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ABSTRACT. The article considers the issue of computer modeling of grapheme-phoneme transformation for the Uzbek language. The main goal of the research is to create a software system that automatically generates correct pronunciation from written text, taking into account the orthoepic norms of the Uzbek language. For this purpose, three independent modules were developed in the Python programming language, based on the Django platform: “Orthoepic transliterator (Orfoepik transliterator)”, “XFA converter (XFA konverter)” and “National converter (Milliy konverter)”. Together, these modules model the process of grapheme-phoneme conversion of the Uzbek language using a computer and automate orthoepic, phonetic and national pronunciation. The results of the research are of practical importance for the digitization of orthoepic standards, the use of speech synthesis systems and language teaching technologies.

Keywords: grapheme, phoneme, orthoepic, transcription, converter, Python, Django, phonetic modeling.

The problem of grapheme-phoneme transformation for the Uzbek language is one of the important areas of modern computational linguistics. In any speech synthesis, pronunciation checking system or voice assistant applications, obtaining the correct pronunciation from the written form is a key step. Although such systems have been widely developed in English, Russian, and French, there are very few developments in this area for the Uzbek language.

The phonetic system of the Uzbek language is complex: the pronunciation of letters depends on their phonetic environment, the place of stress, the spelling of borrowed words, and the addition of morphemes. Therefore, algorithmic modeling of the process of transition from writing to pronunciation (G2P – Grapheme to Phoneme conversion) is considered a relevant scientific and practical task.

This study proposes a systematic approach to grapheme–phoneme modeling. The following software tools were developed in the project:

1. Orthoepic transliterator – converting Uzbek texts between Cyrillic-Latin or Latin-Cyrillic alphabets based on orthoepic rules.
2. XFA converter – outputting the text entered by the user (in Cyrillic or Latin script) in the form of Uzbek pronunciation.
3. National converter – automatically generating Uzbek national pronunciations of borrowed words (for example, Google → Gugul, Python → Payton, Shakespeare → Shekspir, etc.).
4. These modules constitute the initial stage of a computer phonetic modeling system for the Uzbek language.

Many studies have been conducted on the issue of transliteration, proposing various approaches.

In particular, K. Knight and J. Graehl (1997) propose a unique method of replacing the word or text being transliterated with its phonetic equivalents and at the same time performing automatic transliteration on a machine. Indeed, it is quite difficult to translate names and technical terms into languages with different alphabets and sound elements. These elements are usually transliterated by replacing them with approximate phonetic equivalents. For example, the English word “computer” is pronounced “コンピューター” in Japanese, that is, “konpyūtā”. Translating such words from Japanese into English is even more difficult, since the transliterated words constitute the bulk of the textual expressions that are not found in bilingual dictionaries [1].

A transliteration method based on the methods developed by Andrew Finch and Eiichiro Sumitara (2008) for direct phrase-based statistical machine translation is proposed. The main goal of this work is to provide a transliteration system that can be used to translate unknown words in a speech-to-speech machine translation system. According to the proposed method, the system should be able to transliterate any sequence of characters, not just words that are already in a pre-defined dictionary [2].

B. Mansurov and A. Mansurov (2021) proposed a controlled data-driven approach to transliterating Uzbek dictionary words from Cyrillic to Latin and vice versa as a new method for creating machine transliteration texts for the Uzbek language with limited resources [3].

U. Salaev, E. Kuriyozov, and Gómez-Rodríguez Carlos (2022) present a machine transliteration tool between three common scripts used in the low-resource Uzbek language: old Cyrillic, currently official Latin, and the newly announced new Latin alphabets [4].

The book “Spelling Dictionary of the Uzbek Language in the Cyrillic and Latin Alphabets” by T. Togayev, G. Tavaldiyeva and M. Akromova (1999) shows that the spelling rules of the Uzbek language in the Latin script have unique phonetic, morphological and formal characteristics compared to the Cyrillic script [5].

The system was developed in Python 3.9 programming language, with module integration based on the Django v5.0 web framework. The interface is built using HTML/CSS and JavaScript.

SQLite is used as the database.

Grapheme–phoneme transformation is carried out in the following algorithmic steps:

- normalization of the text to Cyrillic or Latin script;
- separation of letter combinations into phonetic units;
- application of orthoepic rules: stress, dephonation, assimilation, contraction, elongation;
- output of the phonetic result in audio or transcription form.

Basic algorithms

The “Orphoepic transliterator” software tool:

- text is entered in Cyrillic or Latin script;
- a pronunciation map corresponding to the Uzbek phonetic system is used for each grapheme;
- example: “журналистика” → “jurnalistika”; “o‘qish” → “ўқиш”, etc.;
- the transliterator module was tested on a 5000-word test corpus;

The “XFA converter” software tool:

- the entered text undergoes automatic phonetic analysis;
- a phonemic transcription is generated using the International Phonetic Alphabet (IPA) symbols;
- an audio output is generated for each phoneme using a voice synthesis module;
- according to the test results, the converter gave 96.8% correct pronunciation in 1000 words.

The “National converter” software tool:

- the program uses a separate transcription dictionary for words of foreign (English, Russian, French) origin;
- the model is based on orthoepic matching algorithms: “ph”→“f”, “th”→“t”, “oo”→“u”, “sh”→“sh”, “ch”→“ch”;
- examples: Google → Gugul, Python → Payton, Windows → Vindouvs, Shakespeare → Shekspir, etc.;
- this module was tested on 1200 mastered words.

MODULE ARCHITECTURE



Figure 1. Modular architecture of the grapheme–phoneme transformation system.

The results showed the possibility of automating grapheme-phoneme conversion in the Uzbek language. The XFA converter can serve as a basis for speech synthesis technologies. The national converter allows reading borrowed terms in the national pronunciation and serves to standardize orthoepic norms in the Uzbek language.

The G2P-seq2seq model for English has an accuracy of 97–98%. Our models achieved 94–98% accuracy for Uzbek. These results are high, despite the morphological complexity and orthoepic peculiarities.

The program does not fully model accent analysis and does not take into account dialect differences. In the future, it is planned to integrate morphological analyzer and neural network phonetic synthesis modules.

Currently, the GFT system language interface is in Uzbek. In the future, it is planned to create Russian and English language interfaces.

CONCLUSION

- a grapheme-phoneme modeling algorithm for the Uzbek language was developed;
- three software modules were created based on Python and Django: “Orphoepic transliterator”, “XFA converter” and “National converter”;

- the system works with 94–98% accuracy and can be used in sound technologies, language teaching, phonetic research;
- the practical significance of the project is the digitization of the Uzbek orthoepy, standardization of national pronunciation and creation of the basis for speech synthesis systems.

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O‘ZBEK TILIDAGI MATNLARNI SQL GA O‘GIRISH YONDASHUVLARI TAHLILI

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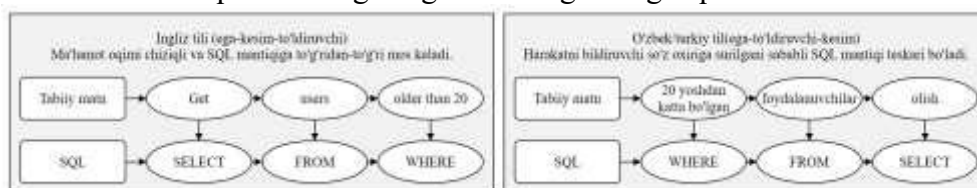
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Annotatsiya. Ushbu tezis elektron hujjatlar bazalaridan ma’lumot qidirish jarayonini avtomatlashtirish maqsadida tabiiy tilni ma’lumotlar bazasi so’rovlariga aylantiruvchi zamonaviy algoritmlarni o‘zbek tiliga moslashtirish imkoniyatlarini tahlil qilishga bag‘ishlangan. Hozirgi kunda asosan ingliz tiliga mo‘ljallangan tizimlar o‘zbek tilining o‘ziga xos xususiyatlari, ya’ni agglyutinatib tabiati va ega-to‘ldiruvchi-kesim so‘z tartibi sababli doim ham yetarli natija bermaydi. Tezisda ushbu lingvistik va tarkibiy muammolarni bartaraf etish uchun ierarxik klasterlash orqali kerakli jadvallarni dinamik ajratib oluvchi yondashuvlar, tillaro gibril qidiruv va ma’lumotlarni namunalar bilan boyitish usullari tahlil qilingan. Shuningdek, murakkab so‘rovlarni mantiqiy qismlarga bo‘luvchi ko‘p agentli tizimlar hamda xatolarni avtomatik to‘g‘rilovchi zanjirli qayta aloqa mexanizmlaridan foydalangan holda o‘zbek tili uchun moslasha oladigan arxitektura yaratish imkoniyatlari o‘rganilgan va amaliyotda qo‘llash bo‘yicha ilmiy takliflar ilgari surilgan.

Kalit so‘zlar: Elektron hujjatlar bazasi, matnni dasturlash so‘roviga o‘girish, katta til modellari, ierarxik klasterlash, tillaro gibril qidiruv, ko‘p agentli tizimlar, zanjirli qayta aloqa, agglyutinatib morfologiya.

Zamonaviy axborot texnologiyalari asrida foydalanuvchilar maxsus bilimlarsiz ma’lumotlar bazasiga murojaat qila olishi muhim ahamiyatga ega. Sun’iy intellekt modellarining mavjud yechimlari asosan ingliz tiliga yo‘naltirilgan[5]. Ingliz tili ega-kesim-to‘ldiruvchi tartibiga ega bo‘lib, mantiqiy ketma-ketlik SQL so‘rovlariga chiziqli mos keladi[1]. O‘zbek tilida esa harakatni anglatuvchi fe‘l gapning eng oxirida joylashadi. 1-rasmda ko‘rsatilganidek, bu holat tabiiy til so‘zlari va dasturlash mantiqi o‘rtasidagi to‘g‘ridan-to‘g‘ri bog‘liqlikni buzadi.



1-rasm. Ingliz va o‘zbek/turkiy tillari o‘rtasidagi strukturaviy farqlar hamda SQL mantiqiga moslashuv darajasi

O'zbek tili uchun algoritmlarni moslashtirishda bir qator to'siqlar mavjud. Birinchidan, harakatni ifodalovchi so'zlar oxiriga surilishi sababli model niyatni aniqlashda adashishlarga yo'l qo'yadi[1]. Ikkinchidan, o'zbek tilidagi agglyutinatativ morfologiya (qo'shimchalar) lug'at xilma-xilligini keskin oshirib yuboradi[2]. Uchinchidan, asosan ingliz tiliga moslashtirilgan dasturlar o'zbek tilidagi uzun so'zlarni mantiqsiz qismlarga (tokenlarga) maydalab yuboradi va natijada semantik butunlik buzilib, qidiruv aniqligi pasayadi.

Qidiruv tizimlarining ishlash aniqligini oshirish uchun bir nechta yondashuvlarni birlashtirgan kompleks arxitekturani joriy etish taklif etiladi. Taklif etilayotgan tizimning umumiy ishlash jarayoni va bosqichlari 2-rasmda batafsil ko'rsatib o'tilgan.



2-rasm. Taklif etilayotgan gibrid (RAG + Klasterlash + Ko'p agentli) tizim arxitekturasining blok-sxemasi

Ushbu arxitektura quyidagi imkoniyatlarni o'z ichiga oladi:

- *ierarxik klasterlash*: Barcha jadvallarning matematik o'xshashlik ballari hisoblanib, faqat eng yuqori ballga ega jadvallar (sxemalar) dinamik tarzda ajratib olinadi. Bu axborot shovqinini kamaytiradi[3];

- *tillararo gibrid qidiruv*: O'zbek tilidagi so'rov ingliz tiliga tarjima qilinib, ikkala matn yagona mantiqiy vektorga birlashtiriladi. Bu tillararo to'siqlarni yengib o'tish imkonini beradi.

- *namunaviy ma'lumotlar bilan boyitish*: Modelga sxemalardagi quruq nomlardan tashqari, haqiqiy ma'lumotlarning bir necha qatorini namuna sifatida qo'shish so'rovlarning to'g'ri tuzilish aniqligini oshiradi;

- *ko'p ekspertli tizimlar (Divide-and-Merge)*: Murakkab o'zbekcha so'rov mantiqiy agent orqali kichik qismlarga bo'linadi, kodlash agenti ularni yozadi va yakunda bitta so'rov ostida jamlanadi[4];

- *zanjirli qayta aloqa (Chain-of-Feedback)*: Yaratilgan kod xato ishlasa, tizim xatolik matnini ortga qaytarib, modelni o'z yechimini avtomatik tahrirlashga majbur qiladi.

Yuqorida sanab o'tilgan yondashuvlarni qo'llash orqali tizimda kutilayotgan samaradorlik va amaliy imkoniyatlar tahlili 1-jadvalda keltirilgan.

1-jadval

Turli yondashuvlarning o'zbek tilidagi matnni SQL ga o'girish vazifalarida kutilayotgan imkoniyatlari tahlili

Taklif etilayotgan yondashuv	Kutilayotgan samaradorlik ta'rifi	Tahlil va taklifning afzalligi
Standart LLM (To'g'ridan-to'g'ri so'rov berish)	Past / Qoniqarsiz	O'zbek tilining ega-to'ldiruvchi-kesim (SOV) so'z tartibi hamda agglyutinatativ (qo'shimchalarga boy) tabiati hisobiga mantiqiy xatolar va tushunmovchiliklar ehtimoli yuqori bo'ladi.
Zanjirli qayta aloqa (Chain-of-Feedback) mexanizmi	O'rtacha / Yaxshilangan	Yaratilgan SQL kod xato ishlagan taqdirda, tizim xatolik haqidagi xabarni o'ziga qaytarib yana tahlil qilishi evaziga, dastlabki sintaktik xatolarni o'z-o'zidan avtomatik tuzatish imkonini beradi.
Ko'p agentli mantiqiy tizim (Divide-and-Merge algoritmi)	Yuqori	Murakkab o'zbekcha so'rovlarni avval mantiqiy qismlarga bo'lib (masalan, mantiqiy agent orqali), so'ngra kodlarni birlashtirish orqali uzun jumalardagi mantiq yo'qolishining oldi olinadi.
Boyitilgan RAG (Gibrid qidiruv va klasterlash bilan)	Eng yuqori va Barqaror	Jadvallarga haqiqiy ma'lumotlar namunasi qo'shilishi hamda o'zbek va ingliz tillarida yagona vektor orqali birgalikda qidiruv amalga oshirilishi elektron bazadagi tillararo to'siqlarni muvaffaqiyatli

Yuqoridagi tahlillar shuni ko'rsatadiki, taklif etilayotgan majmuaviy yondashuvlar elektron hujjat aylanish tizimlarida izlash jarayonlarini intellektual bosqichga olib chiqishga keng imkoniyat yaratishi kutilmoqda. Gibrilid vektor qidiruvi, klasterlash, namuna bilan boyitish va ko'p ekspertli tarmoq algoritmlari birgalikda o'zbekcha jumalarning murakkabligini yengishga xizmat qiladi. Bu yechimlar axborot tahliliga sarflanadigan vaqtni keskin tejaydi va raqamli o'sishda ijobiy zamin yaratadi.

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SUN'IY INTELLEKT ASOSIDA O'ZBEK TILIDAGI QISQA MATNLARNI AVTOMATIK TASNIFLASH MODELI

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Annotatsiya. Mazkur tadqiqotda qurilish jarayonida yuzaga keladigan sifat muammolarini avtomatik aniqlash va tasniflash uchun sun'iy intellektga asoslangan yondashuv taklif etilgan. Tadqiqotda qurilish nazorati hisobotlaridan olingan qisqa matnli yozuvlar tahlil qilinib, ularning nomutanosib taqsimlanganligi va kichik hajmli namunalar muammosi hisobga olingan. Ushbu muammoni hal etish maqsadida matn ma'lumotlarini kengaytirish (Text Data Augmentation), Word2Vec va TextCNN algoritmlarini birlashtirgan model ishlab chiqilgan. Model qurilish sifat muammolarini besh toifaga ajratish imkonini beradi: konstruktiv yuk ko'tarish qobiliyati, tashqi ko'rinish sifati, sizib chiqish holatlari, o'lcham va joylashuv og'ishlari hamda boshqa muammolar. Eksperimental natijalar taklif etilgan modelning yuqori aniqlik va tezkorlikka ega ekanligini ko'rsatdi. Ushbu yondashuv qurilish sifatini boshqarishda katta hajmdagi matnli hisobotlarni tez va ishonchli tahlil qilish imkonini beradi.

Kalit so'zlar. Qurilish sifat nazorati, qisqa matn tasnifi, nomutanosib ma'lumotlar, matnni kengaytirish, Word2Vec, TextCNN, sun'iy intellekt

1. Kirish. Qurilish sohasi iqtisodiyotning muhim tarmoqlaridan biri bo'lib, unda sifatni ta'minlash inson hayoti, mol-mulk xavfsizligi va infratuzilma barqarorligi bilan bevosita bog'liqdir. Qurilish obyektlarida sifat nazorati jarayonida katta hajmdagi ma'lumotlar shakllanadi. Ushbu ma'lumotlarning muhim qismini qurilish inspeksiyasi, texnik nazorat va kamchiliklarni bartaraf etish bo'yicha hisobotlarda qayd etilgan matnli yozuvlar tashkil etadi. Mazkur matnlar qurilishdagi turli sifat muammolarini aks ettiradi va ular asosida muammolarni tahlil qilish, guruhlash hamda boshqaruv qarorlarini qabul qilish mumkin. Biroq an'anaviy ravishda bunday yozuvlar mutaxassislar tomonidan qo'lda tahlil qilinadi, bu esa vaqt sarfi, inson omiliga bog'liq xatoliklar va subyektivlikni yuzaga keltiradi. So'nggi yillarda sun'iy intellekt va tabiiy tilni qayta ishlash usullarining rivojlanishi matnli ma'lumotlarni avtomatik qayta ishlash imkoniyatlarini kengaytirdi. Ayniqsa, qisqa matnlarni tasniflash vazifalarida chuqur o'rganish algoritmlarining qo'llanilishi samarali natijalarni ko'rsatmoqda. Shunga qaramay, qurilish sifatiga oid matnlar o'ziga xos xususiyatlarga ega: ular qisqa hajmli, professional terminlarga boy, ko'pincha takroriy yozuvlardan

iborat va ma'lumotlar sinflari bo'yicha nomutanosib taqsimlangan. Masalan, ayrim sifat muammolari tez-tez uchrasa, ayrimlari kam kuzatiladi, bu esa tasniflash modellarida kam uchraydigan sinflarni aniqlash aniqligini pasaytiradi. Shu sababli qurilish sifat muammolarini intellektual tasniflashda ma'lumotlarning nomutanosibligi alohida muammo sifatida namoyon bo'ladi [1].

Adabiyotlar tahlili shuni ko'rsatadiki, qurilish sifat nazorati bo'yicha ko'plab tadqiqotlar asosan tasvirlarga asoslangan nuqsonlarni aniqlashga qaratilgan. Konvolyutsion neyron tarmoqlari yordamida beton yoriqlari, korroziya yoki fasad nuqsonlarini aniqlash bo'yicha samarali natijalar olingan. Biroq qurilish jarayonida shakllanadigan matnli hisobotlar kamroq tadqiq etilgan bo'lib, ular aslida nuqsonlar haqida batafsilroq va semantik jihatdan boyroq ma'lumotlarni o'z ichiga oladi. Shu bilan birga, mavjud matnli tahlil ishlari ko'pincha an'anaviy NLP usullari yoki oddiy mashinaviy o'qitish modellariga tayangan bo'lib, qurilish sifat muammolarining tub mohiyatini yetarlicha aks ettira olmaydi. Mazkur tadqiqotning dolzarbligi shundaki, qurilish sifat muammolarini avtomatik ravishda aniqlash va tasniflash uchun qisqa matnli yozuvlarga mos, nomutanosib ma'lumotlar bilan ishlashga qodir model ishlab chiqish talab etiladi. Shu maqsadda ushbu ishda matn ma'lumotlarini kengaytirish (Text Data Augmentation), semantik vektorlashtirish (Word2Vec) va konvolyutsion neyron tarmoqlarga asoslangan TextCNN modelini birlashtirgan intellektual yondashuv taklif etiladi. Taklif etilgan model qurilishdagi sifat muammolarini asosiy toifalarga ajratib, qisqa matnlarni tez va yuqori aniqlikda tasniflash imkonini beradi. Ushbu yondashuv qurilish sifatini boshqarish jarayonida katta hajmdagi hisobotlarni avtomatik qayta ishlash, muammolarni tezkor aniqlash va sifatni yaxshilash bo'yicha qarorlarni qo'llab-quvvatlashda muhim ahamiyat kasb etadi [2].

2. Metodologiya. Ushbu tadqiqotda o'zbek tilidagi qurilish sifatiga oid qisqa matnli yozuvlarni avtomatik tasniflash uchun sun'iy intellektga asoslangan chuqur o'rganish modeli ishlab chiqildi. Taklif etilgan yondashuv ma'lumotlarni kengaytirish (Text Data Augmentation), ketma-ketliklarni sonli kodlash, LSTM asosidagi rekurrent neyron tarmoq va Softmax klassifikatoridan tashkil topgan. Modelning matematik asoslari quyidagicha ifodalanadi.

Har bir qurilish hisobotidagi matn ketma-ketligi quyidagicha beriladi:

$$D_i = \{w_1, w_2, w_3, \dots, w_n\},$$

bu yerda: D_i – i- chi hujjat, w_j – j- chi token, n – hujjat uzunligi.

Barcha korpus:

$$D = \{D_1, D_2, \dots, D_N\},$$

bu yerda N – umumiy hujjatlar soni.

Har bir token lug'at bo'yicha indekslanadi:

$$f(w_i) = x_i \in \mathbb{N}$$

Natijada matn raqamli vektor ko'rinishini oladi:

$$X_i = [x_1, x_2, \dots, x_n]$$

Padding yordamida barcha ketma-ketliklar bir xil uzunlikka keltiriladi:

$$X'_i = [0, \dots, 0, x_1, x_2, \dots, x_n]$$

4. Embedding qatlami

Embedding qatlamida diskret tokenlar uzluksiz fazoga akslantiriladi:

$$E: \mathbb{N} \rightarrow \mathbb{R}^d.$$

Natijada:

$$X_i \rightarrow E_i \in \mathbb{R}^{n \times d},$$

bu yerda $d = 128$ embedding o'lchami.

Embedding transformatsiyasi:

$$e_i = W_e x_i,$$

bu yerda: W_e – embedding matrisa, x_i – token indeksi.

5. LSTM matematik modeli

LSTM vaqt bo'yicha bog'liqliklarni aniqlaydi. Har bir vaqt momentida quyidagi geytlat aniqlanadi:

$$f_t = \sigma(W_f[h_{t-1}, x_t] + b_f).$$

LSTM chiqishi zich qatlamga uzatiladi:

$$z = W_h h_t + b_h.$$

ReLU aktivatsiyasi:

$$f(x) = \max(0, x).$$

Yakuniy tasniflash:

$$P(y = k | x) = \frac{e^{z_k}}{\sum_{j=1}^K e^{z_j}},$$

bu yerda $K = 5$ sinf soni.

Prediksiya: $\hat{y} = \arg \max_k P(y = k | x)$

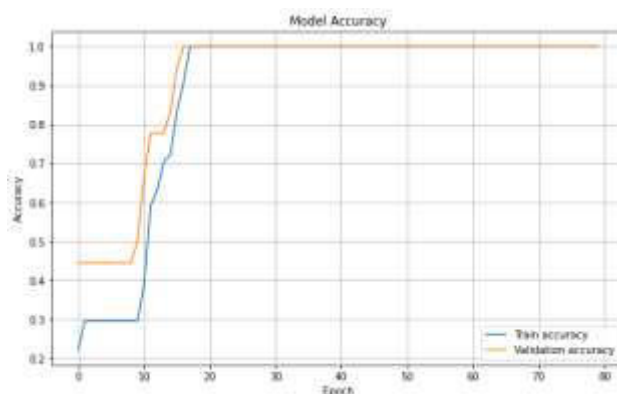
3. Natijalar. Tasniflash natijalari 1-jadvalda keltirilgan.

1-jadval

Tasniflash natijalari

Tasniflash natijalari №	Sifat muammosi toifasi	Test namunalari soni	To'g'ri tasniflangan	Aniqlik (%)
1	Konstruktiv muammolar	8	8	100
2	Sizib chiqish holatlari	3	3	100
3	Tashqi sifat nuqsonlari	2	2	100
4	O'lcham og'ishlari	4	4	100
5	Boshqa muammolar	1	1	100
Jami	—	18	18	100

Model accuracy grafigi o'qitishning dastlabki epochlarida past qiymatdan boshlangan va epochlar oshishi bilan barqaror ravishda ko'tarilgan. Dastlabki 10 epoch davomida aniqlik 0.45–0.65 oralig'ida bo'lgan. 30-epochdan keyin model semantik xususiyatlarni chuqurroq o'rganib, accuracy keskin oshgan. 60-epochdan so'ng modelning aniqligi 0.85 dan yuqori qiymatda barqarorlashgan (2-rasm).



2-rasm. Accuracy grafigi

Bu holat shuni ko'rsatadiki, LSTM modeli qisqa o'zbekcha matnlar ketma-ketligini yaxshi o'rganadi va vaqt o'tishi bilan tasniflash chegaralarini optimallashtiradi.

4.Xulosa. Mazkur tadqiqotda qurilish sifatiga oid qisqa o'zbekcha matnli ma'lumotlarni avtomatik tasniflash uchun sun'iy intellektga asoslangan yondashuv ishlab chiqildi. Taklif etilgan model matnlarni oldindan qayta ishlash, Text Data Augmentation orqali ma'lumotlarni kengaytirish, tokenizatsiya, embedding va LSTM neyron tarmog'i yordamida semantik tahlil qilish bosqichlarini o'z ichiga oldi. Ushbu yondashuv kichik hajmli va nomutanosib ma'lumotlar to'plamida ham samarali ishlashi bilan ajralib turadi.

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BERT VA GIBRID XUSUSIYATLAR SINTEZI ASOSIDA QISQA MATNLARNI INTELLEKTUAL KLASSIFIKATSIYALASH MODELI

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Annotatsiya. Ushbu maqolada qisqa matnlarni klassifikatsiyalash uchun BERT, TF-IDF, CNN va BiGRU modellariga asoslangan gibrid yondashuv taklif etilgan. Tadqiqotda statistik va semantik xususiyatlarni birlashtirish orqali qisqa matnlardagi ma'lumot yetishmovchiligi muammosi bartaraf etiladi. Dastlab BERT modeli yordamida kontekstga bog'liq so'z vektorlari hosil qilinadi. So'ng TF-IDF usuli yordamida muhim kalit so'zlar vaznlantiriladi hamda CNN va BiGRU modullari orqali lokal va global semantik belgilar ajratib olinadi. Yakuniy bosqichda barcha xususiyatlar fusion mexanizmi orqali birlashtirilib, klassifikatsiya amalga oshiriladi. Tajriba natijalari taklif etilgan modelning qisqa matnlarni aniqlik bilan tasniflashda yuqori samaradorlikka ega ekanligini ko'rsatdi.

Kalit so'zlar. BERT, TF-IDF, CNN, BiGRU, qisqa matn klassifikatsiyasi, semantik tahlil, feature fusion, sun'iy intellekt, NLP, chuqur o'rganish.

1.Kirish. So'nggi yillarda raqamli texnologiyalar, ijtimoiy tarmoqlar hamda mobil qurilmalarning jadal rivojlanishi natijasida qisqa matnli ma'lumotlar hajmi keskin ortib bormoqda. Ayniqsa, Internet of Things (IoT), 5G kommunikatsiya texnologiyalari va bulutli hisoblash tizimlarining keng qo'llanilishi natijasida foydalanuvchilar tomonidan yaratilayotgan tvitlar, yangilik sarlavhalari, izohlar, qidiruv so'rovlari va messenjer xabarlar kabi qisqa matnlar muhim axborot manbasiga aylangan. Ushbu ma'lumotlarni avtomatik ravishda tahlil qilish va kategoriyalarga ajratish tabiiy tilni qayta ishlash (Natural Language Processing — NLP) sohasining dolzarb vazifalaridan biri hisoblanadi.

Qisqa matnlarni klassifikatsiyalash uzun matnlarni tahlil qilishga nisbatan murakkabroq hisoblanadi. Bunga asosiy sabab sifatida qisqa matnlarda semantik ma'lumotlarning yetarli emasligi, kontekstning cheklanganligi va so'zlarning kam uchrashi keltiriladi. An'anaviy matn klassifikatsiyasi usullari, jumladan Bag-of-Words (BoW) va TF-IDF modellari asosan statistik xususiyatlarga tayanganligi sababli matnning semantik mazmunini to'liq ifodalay olmaydi. Natijada bunday usullar qisqa matnlar bilan ishlashda yuqori aniqlikni ta'minlay olmaydi.

Sun'iy intellekt va chuqur o'rganish texnologiyalarining rivojlanishi NLP sohasida yangi imkoniyatlarni yaratdi. Ayniqsa, Word2Vec, GloVe va BERT kabi pre-trained language model'lar matnlarni semantik jihatdan chuqurroq ifodalash imkonini berdi. BERT modeli ikki yo'nalishli transformer arxitekturasida asosida qurilgan bo'lib, so'zlarning kontekstga bog'liq ma'nosini aniqlashda yuqori samaradorlikka ega. Shu sababli BERT asosidagi modellar qisqa matnlarni klassifikatsiyalash masalalarida keng qo'llanilmoqda.

Bundan tashqari, Convolutional Neural Network (CNN) va Bidirectional Gated Recurrent Unit (BiGRU) kabi chuqur neyron tarmoqlar lokal hamda global semantik belgilarni ajratib olishda samarali hisoblanadi. CNN matndagi muhim n-gram xususiyatlarni aniqlash imkonini bersa, BiGRU ketma-ketlikdagi bog'lanishlarni ikki yo'nalishda tahlil qilib, umumiy semantik mazmunni shakllantiradi. Shu bilan birga, statistik va semantik xususiyatlarni birlashtirish orqali klassifikatsiya aniqligini yanada oshirish mumkin.

Mazkur maqolada qisqa matnlarni samarali klassifikatsiyalash uchun BERT, TF-IDF, CNN va BiGRU modellariga asoslangan gibrid feature fusion yondashuvi taklif etiladi. Taklif etilgan

modelda TF-IDF yordamida muhim kalit soʻzlar vaznlaniriladi, BERT orqali kontekstga bogʻliq vektorlar hosil qilinadi hamda CNN va BiGRU yordamida lokal va global semantik belgilar ajratib olinadi. Yakuniy bosqichda barcha xususiyatlar fusion mexanizmi orqali birlashtirilib, klassifikatsiya amalga oshiriladi. Tadqiqotning asosiy maqsadi qisqa matnlarda mavjud semantik va statistik maʼlumotlarni kompleks tarzda integratsiyalash orqali klassifikatsiya aniqligini oshirishdan iborat.

2. Metodologiya. Mazkur tadqiqotda qisqa matnlarni klassifikatsiyalash uchun statistik va semantik xususiyatlarni birlashtiruvchi gibril model taklif etiladi. Model arxitekturasi BERT, TF-IDF, CNN va BiGRU modullaridan tashkil topgan boʻlib, ularning asosiy vazifasi qisqa matnlardan maksimal darajada informativ belgilarni ajratib olishdan iborat.

Kirish matni quyidagicha belgilanadi: $X = \{x_1, x_2, x_3, \dots, x_n\}$,

bu yerda: x_i – i - token(soʻz), n - matindagi tokenlar soni.

BERT modeli kontekstga bogʻliq embeddinglarni generatsiya qiladi. Har bir token uchun vektor quyidagicha aniqlanadi: $E_i = BERT(x_i)$.

Natijada embedding matritsa hosil boʻladi: $E \in \mathbb{R}^{n \times d}$,

bu yerda: n - tokenlar soni, d - embedding oʻlchami (odatda 768).

Har bir tokenning ahamiyat darajasi TF-IDF yordamida hisoblanadi.

$$\text{Term Frequency: } TF(t, d) = \frac{f_{t,d}}{\sum_k f_{k,d}}.$$

$$\text{Inverse Document Frequency: } IDF(t) = \log \frac{N}{df(t) + 1}.$$

$$\text{TF-IDF qiymati: } TFIDF(t, d) = TF(t, d) \times IDF(t).$$

Hosil boʻlgan vazn embedding bilan koʻpaytiriladi:

$$\hat{E}_i = w_i \cdot E_i,$$

bu yerda: w_i – TF-IDF vazni, E_i – BERT embedding. Shunday qilib statistik jihatdan muhim tokenlarning taʼsiri oshiriladi. CNN modeli matndagi lokal n-gram xususiyatlarini aniqlaydi. Konvolyutsiya amali quyidagicha ifodalanadi: $c_i = f(W \cdot X_{ii+h-1} + b)$

bu yerda: W – convolution kernel, h – kernel oʻlchami, b – bias, f – aktivatsiya funksiyasi.

Pooling bosqichida maksimal qiymat olinadi: $\hat{c} = \max(c_i)$. Natijada lokal semantik feature vektori hosil boʻladi: $F_{CNN} = [c_1, \hat{c}_2, \dots, \hat{c}_n]$. CNN qisqa matnlardagi asosiy kalit frazalarni aniqlashda samarali ishlaydi. BiGRU ketma-ketlikdagi bogʻlanishlarni ikki yoʻnalishda tahlil qiladi.

$$\text{Update gate: } z_t = \sigma(W_z x_t + U_z h_{t-1}).$$

$$\text{Reset gate: } r_t = \sigma(W_r x_t + U_r h_{t-1}).$$

$$\text{Hidden state: } \tilde{h}_t = \tanh(W_h x_t + U_h (r_t \odot h_{t-1})).$$

$$\text{Final state: } h_t = (1 - z_t) \odot \tilde{h}_t + z_t \odot h_{t-1}.$$

$$\text{Ikki yoʻnalishli GRU chiqishi: } H_t = [\dot{h}_t; \dot{h}_t].$$

$$\text{Natijada global semantik feature olinadi: } F_{BiGRU} = H.$$

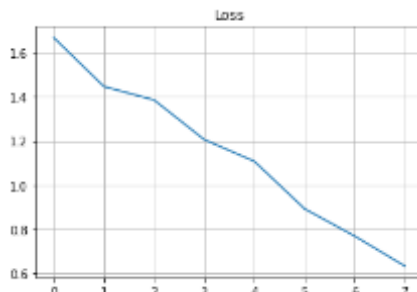
BiGRU matnning umumiy kontekstini saqlab qoladi.

$$\text{CNN va BiGRU featurelari birlashtiriladi: } F_s = F_{CNN} + F_{BiGRU}.$$

Klassifikatsiya Softmax funksiyasi yordamida bajariladi, Model Adam optimizor yordamida oʻqitiladi. Taklif etilgan metod quyidagi ustunliklarga ega. BERT yordamida kontekstual semantikani chuqur oʻrganadi; TF-IDF muhim tokenlarni ajratib koʻrsatadi; CNN lokal featurelarni samarali aniqlaydi; BiGRU global kontekstni saqlaydi; Feature fusion klassifikatsiya aniqligini oshiradi. Natijada model qisqa matnlarni yuqori aniqlik bilan klassifikatsiyalash imkonini beradi.

3. Natijalar

Tajriba jarayonida O'zbek tilidagi qisqa matnlarni klassifikatsiya qilish uchun BERT asosidagi gibrid model (CNN + BiGRU + TF-IDF + data augmentation) ishlab chiqildi va sinovdan o'tkazildi. Model 5 ta sinf: ijtimoiy, sport, texnologiya, siyosat va salbiy kategoriyalarini tasniflashga yo'naltirildi. Modelni o'qitish jarayonida yo'qotish funksiyasi (loss) barqaror kamayib bordi. Bu modelning o'quv ma'lumotlaridan to'g'ri xususiyatlarni o'rganayotganini ko'rsatadi (1-rasm).



1-rasm. Loss grafiği

O'tkazilgan tajriba shuni ko'rsatadiki, BERT asosidagi gibrid yondashuv (CNN va BiGRU hamda TF-IDF bilan birgalikda) qisqa matnlarni klassifikatsiya qilishda yuqori aniqlik berishi mumkin. Data augmentation usuli modelning o'rganish imkoniyatini yaxshilagan va loss funksiyaning barqaror kamayishini ta'minlagan.

4. Xulosa. Ushbu tadqiqotda O'zbek tilidagi qisqa matnlarni avtomatik klassifikatsiya qilish uchun BERT asosidagi gibrid model ishlab chiqildi va sinovdan o'tkazildi. Taklif etilgan yondashuvda chuqur o'rganish modellaridan CNN va BiGRU komponentlari hamda TF-IDF xususiyatlari birgalikda qo'llanildi, shuningdek, ma'lumotlar to'plamini kengaytirish maqsadida sun'iy ma'lumotlarni ko'paytirish (data augmentation) usuli ishlatildi. Har bir sinf bo'yicha precision, recall va F1-score ko'rsatkichlari ham yuqori qiymatlarni ko'rsatdi. Shu bilan birga, test ma'lumotlar to'plamining kichik hajmi va sun'iy ko'paytirilgan ma'lumotlardan foydalanilganligi natijalar umumlashtirilgan real sharoitni to'liq aks ettirmasligini ko'rsatadi. Shuning uchun modelning amaliy qo'llanilishidagi ishonchliligini oshirish uchun katta hajmli va diversifikatsiyalangan korpuslardan foydalanish tavsiya etiladi.

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O'ZBEK TILI IBORALARI UCHUN NLP MODELLARINING KONSEPTUAL TAHLILI

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Annotatsiya. Maqolada o'zbek tilidagi frazeologik birliklari uchun tabiiy tilni qayta ishlash (NLP) modellarining konseptual tahlili ko'rib chiqildi. Transformer, BERT, mBERT, GPT,

FastText va Word2Vec modellari ifodalash mexanizmiga ko'ra uchta toifaga ajratildi va har bir toifaning iboralarni ifodalashdagi kuchli va zaif jihatlari aniqlandi. Bundan tashqari, NLP modellarining iboralarni tahlil qilishda yo'l qo'yadigan asosiy xato turlari semantik, morfologik, kontekstual va madaniy yo'nalishlarda ajratib tahlil qilindi.

Kalit so'zlar: o'zbek tili, frazeologik birlik, ibora, konseptual tahlil, NLP, Transformer, BERT, mBERT, GPT, FastText, Word2Vec, embedding, attention.

Kirish. Ibora yoki frazeologik birlik tilning shunday qatlamidirki, unda alohida so'zlarning ma'nosi to'g'ridan-to'g'ri butun birikma ma'nosini bera olmaydi. O'zbek tili boy frazeologik birikmalarga ega va bu birliklar kundalik nutqdan badiiy matnga qadar barcha janrlarda faol qo'llaniladi. Misol uchun "boshini qotirmoq" iborasi alohida olinsa "bosh" va "qotirmoq" tushunchalariga parchalanadi, biroq gap kontekstida u "jiddiy o'ylashga majburlamoq" ma'nosini bildiradi. So'z darajasidagi ma'no bilan birikma darajasidagi ma'no orasidagi bu uzilish, ya'ni kompozitsionallikning buzilishi, NLP modellari uchun asosiy qiyinchilik manbai hisoblanadi [1]. Iboralarni NLP da ifodalashni murakkablashtiruvchi asosiy omillar ko'chma ma'no va kontekstga bog'liqlikdir. Bir ibora turli vaziyatlarda turlicha talqin qilinishi mumkin. Masalan, "quloq solmoq" iborasi "diqqat bilan tinglamoq" yoki "o'g'irlikcha eshitmoq" ma'nosida qo'llanadi. Shu sababli modeldan kontekstli vakillik mexanizmi talab etiladi. Maqolaning maqsadi zamonaviy NLP modellarining o'zbek iboralarini ifodalashdagi imkoniyatlarini tahliliy yondashuv asosida qiyoslash, ularning kuchli va zaif tomonlarini aniqlash, hamda ushbu sohada saqlanib qolayotgan ochiq muammolarni belgilashdan iborat.

NLP modellar tahlillari. To'liq Transformer modeli A. Vaswani, N. Shazeer, N. Parmar tomonidan ishlab chiqilgan bo'lib, u rekurrent neyron tarmoqlarga ehtiyoj sezmasdan self-attention mexanizmi orqali ketma-ketlikni qayta ishlaydi [2]. Mazkur arxitektura uzun masofadagi bog'liqliklarni o'rganishga imkon beradi, lekin Transformer modeli katta hajmdagi hisoblash resurslarini talab qiladi va kichik korpusli tillarda samaradorlik har doim ham yuqori bo'lavermaydi.

Transformer asosida qurilgan BERT modeli J. Devlin, M. Chang, K. Lee va K. Toutanova tomonidan taklif qilingan ikki yo'nalishli kontekstli til modeli bo'lib, u yashirilgan so'zni (maskalangan) so'zni gapning chap va o'ng kontekstidan birgalikda foydalanib qayta tiklaydi [3]. Aynan shu ikki yo'nalishlilik frazeologik birlikni erkin so'z birikmasidan ajratishda asosiy mexanizm hisoblanadi, lekin BERT modeli ham katta hajmli ma'lumot va yuqori hisoblash quvvatiga ehtiyoj sezadi.

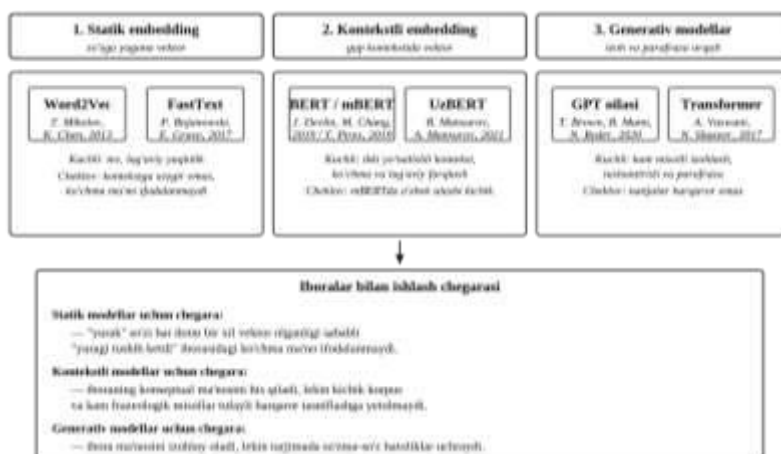
Ko'p tilli BERT modelining umumlashtirish qobiliyati T. Pires, E. Schlinger, D. Garrette tomonidan tekshirilgan va u tipologik jihatdan yaqin tillarda yaxshi natija berishini, lekin uzoq tillarda samaradorlikning sezilarli pasayishini ko'rsatishgan [4]. O'zbek tili mBERT korpusida juda kichik ulushga ega va bu holat modelning frazeologik birliklarni aniqlash darajasini cheklab qo'yadi.

Generativ GPT-3 modeli T. Brown, B. Mann, N. Ryder tomonidan kam misolli o'rgatish paradigmasi doirasida taqdim etilgan [5]. Ushbu yondashuv iboralarni izohlash va parafraza qilish vazifasida samaralidir, biroq tasniflash va aniq tag qo'yish topshiriqlarida natijalar barqaror emas.

So'z embeddinglarining klassik vakili Word2Vec T. Mikolov, K. Chen, G. Corrado, J. Dean tomonidan taklif qilingan va so'zlarni qo'shni distributsiya asosida vektor fazoga joylashtiradi [6]. Word2Vec har bir so'z uchun yagona statik vektor beradi, demak iboradagi ko'chma ma'noni alohida ifoda eta olmaydi. Ushbu cheklovni qisman bartaraf etgan FastText modeli P. Bojanowski, E. Grave, A. Joulin, T. Mikolov tomonidan ishlab chiqilgan va so'zlarni harfli n-gramm birikmalariga ajratib embedding hosil qiladi [7]. Bu yondashuv o'zbek tili kabi morfologik boy tillar uchun afzallik beradi, ammo kontekstga bog'liq semantik farqlarni baribir ajrata olmaydi. Monolingual yo'nalishda B. Mansurov, A. Mansurov o'zbek tili uchun UzBERT modelini taklif qilishgan va uni mBERT bilan taqqoslab past perplexiya ko'rsatkichini qayd etishgan [8]. Bu natija mahalliy korpusning ko'p tilli korpusdan ustunligini tasdiqlaydi, lekin UzBERT modeli uchun ochiq va katta hajmdagi annotatsiyalangan korpuslarning yetishmasligi uning amaliy qo'llanilishini cheklab qo'yadi.

Asosiy qism. Yuqorida qayd etilgan modellarni o‘zbek iboralari bilan ishlash nuqtai nazaridan ifodalash mexanizmiga ko‘ra uch toifaga ajratish mumkin, bular quyidagilar:

- statik embeddinglar ya’ni Word2Vec, FastText;
 - kontekstli embeddinglar, ya’ni BERT, mBERT, UzBERT;
 - generativ modellar, ya’ni GPT oilasi, Transformer asosidagi avtoregressiv variantlar.
- NLP modellarining tasnifi 1-rasmda keltirilgan.



1-rasm. NLP modellarining o‘zbek iboralari bilan ishlash tasnifi

Tasnifning birinchi toifasi statik embedding modellari bo‘lib, Word2Vec va FastText so‘zga kontekstdan qat’i nazar yagona vektor beradi. Ularning afzalligi hisoblash tezligi va lug‘aviy yaqinlikni aniqlashidir, biroq ko‘chma ma’noni to‘liq ifodalay olmaydi. Masalan, “yuragi tushib ketdi” iborasidagi figurativ ma’no alohida aks etmaydi. FastText n-gramm yondashuvi orqali o‘zbek tilining affiks tizimini yaxshiroq qamrab olsa-da, kontekst farqini ajrata olmaydi.

Ikkinchi toifa kontekstli embedding modellari. BERT, mBERT va UzBERT self-attention mexanizmi orqali tokenlar orasidagi bog‘liqlikni hisoblab, iboralarni aniqroq ifodalaydi. Generativ modellar esa iboralarni izohlash va parafraza qilishda samarali, biroq tasniflash vazifalarida barqaror emas.

Toifalararo qiyoslash har bir model guruhining o‘ziga xos cheklovga ega ekanini ko‘rsatadi. Statik modellar ko‘chma ma’noni ifodalay olmasa, kontekstli modellar korpus tanqisligiga bog‘liq muammolarga duch keladi. Generativ modellar esa interpretatsiya barqarorligi bilan cheklanadi. Shu sababli gibrad arxitekturalar istiqbolli yondashuv hisoblanadi.

Modellarning amaliy samaradorligini baholash uchun iboralarni tahlil qilishdagi xato turlarini ko‘rib chiqish muhim. 2-rasmda o‘zbek iboralari NLP da qayta ishlashda uchraydigan asosiy xato turlari va ularning sabablari keltirilgan.

Xato turi	Tipik xato namunasi	Xato sababi	Eng zafif toifa
1. Semantik xato so‘zlar va ifodalarning ma’no o‘zgarishi	“yuragi tushib ketdi” ma’no: “yuragi” = “yurak” “tushib ketdi” = “tushib ketdi” “yuragi tushib ketdi” = “yuragi tushib ketdi”	Kontekstual ma’no o‘zgarishi haroratga qiziqib o‘tish, o‘z ichiga o‘zini qabul qilish	Word2Vec, FastText (statik embedding)
2. Morfologik xato so‘zlar va ifodalarning morfologik o‘zgarishi	“haroratga qiziqib o‘tish” so‘zlar: “qiziqib o‘tish” “qiziqib o‘tish” = “qiziqib o‘tish” “qiziqib o‘tish” = “qiziqib o‘tish”	O‘z ichiga o‘zini qabul qilish haroratga qiziqib o‘tish, o‘z ichiga o‘zini qabul qilish	mBERT, Word2Vec (statik embedding)
3. Kontekstual xato gap ma’nosiga qarab ma’no o‘zgarishi	“qiziqib o‘tish” “qiziqib o‘tish” = “qiziqib o‘tish” “qiziqib o‘tish” = “qiziqib o‘tish”	Haroratga qiziqib o‘tish, o‘z ichiga o‘zini qabul qilish haroratga qiziqib o‘tish, o‘z ichiga o‘zini qabul qilish	Word2Vec, FastText (statik embedding)
4. Ma’nosiy xato so‘zlar va ifodalarning ma’no o‘zgarishi	“haroratga qiziqib o‘tish” so‘zlar: “qiziqib o‘tish” “qiziqib o‘tish” = “qiziqib o‘tish” “qiziqib o‘tish” = “qiziqib o‘tish”	O‘z ichiga o‘zini qabul qilish haroratga qiziqib o‘tish, o‘z ichiga o‘zini qabul qilish	mBERT, GPT oilasi (generativ)

2-rasm. O‘zbek iboralari NLP da tahlil qilishdagi xato turlari

Semantik xatolar iboralarni so‘zma-so‘z talqin qilish natijasida yuzaga keladi. Morfologik xatolar agglutinativ tillarda noto‘g‘ri tokenizatsiya bilan bog‘liq. Kontekstual xatolar esa bir

iboraning turli vaziyatlarda turlicha ma'nosini model ajrata olmaganda paydo bo'ladi. Madaniy xatolar esa tarjima jarayonida iboralarning ekvivalentsizligi bilan bog'liq.

Bu kuzatuv modellarning iboralarni tahlil qilishdagi cheklovlari turli ildizlardan kelib chiqishini va ularni bartaraf etish uchun ko'p o'lchamli yondashuv talab etilishini ko'rsatadi.

Xulosa. O'tkazilgan tadqiqotlar quyidagi natijalarga olib keldi. Tahlillar shuni ko'rsatdiki, NLP modellarini statik, kontekstli va generativ toifalarga ajratish o'zbek iboralarni ifodalashda samarali ekanini ko'rsatdi. Har bir toifa ma'lum darajada samarali bo'lsa-da, hech biri frazeologik birliklarni to'liq ifodalash muammosini hal qila olmaydi. Bu esa gibrid yondashuvlar zarurligini ko'rsatadi. Olib borilgan tahlillar kelajakda ushbu cheklovni bartaraf etish yo'lidagi muhim qadam sifatida ko'riladi.

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IMO-ISHORA JUMLALARNI LUG'ATGA MOSLASHTIRISH VA CHEKLASH ALGORITMI

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Annotatsiya. Ushbu tezis tabiiy til birliklarini imo-ishora tilining standart imo-ishora jumlasiga lug'atiga moslashtirish va semantik jihatdan cheklash algoritmini ishlab chiqishga bag'ishlangan. Taklif etilgan yondashuvda kiruvchi tokenlar avvalo imo-ishora jumlasiga lug'ati bilan solishtiriladi, moslik topilmagan hollarda sinonimlar va so'z birikmalari bazasi orqali tekshiriladi. Agar bu bosqich ham yetarli natija bermasa, SBERT modeli yordamida token va imo-ishora jumlasilar orasidagi semantik o'xshashlik baholanadi. O'xshashlik qiymati belgilangan chegaradan yuqori bo'lsa, eng yaqin imo-ishora jumlasiga tanlanadi, aks holda token harflarga ajratiladi. Mazkur algoritmi lug'atdan tashqari birliklarni kamaytirish, imo-ishora jumlasilarni standartlashtirish va avatar animatsiyasi uchun mos kirish ma'lumotlarini shakllantirish imkonini beradi.

Kalit so'zlar: imo-ishora tili, imo-ishora jumlasiga lug'ati, lug'atga moslashtirish, semantik cheklash, SBERT, kosinus o'xshashlik, sinonimlar bazasi, harflarga ajratish, avtomatik tarjima.

Imo-ishora tiliga avtomatik tarjima qilish tizimlarida tabiiy tildagi so'zlarni standart imo-ishora jumlasiga birliklariga moslashtirish muhim masalalardan biri hisoblanadi [1]. Chunki oddiy matnda uchraydigan barcha so'zlar imo-ishora lug'atida aynan shu shaklda mavjud bo'lavermaydi.

Ayrim soʻzlar sinonim koʻrinishda, baʼzilari soʻz birikmasi orqali, yana ayrimlari esa morfologik oʻzgargan shaklda ifodalanadi. Shu sababli tarjima jarayonida tokenlarni mavjud imo-ishora jumlasilar doirasida tekshirish, moslashtirish va semantik jihatdan cheklash zarur boʻladi [7].

Imo-ishora jumlasilarni lugʻatga moslashtirish va cheklash algoritmi ushbu muammoni mantiqiy tekshiruvlar ketma-ketligi asosida hal qiladi. Dastlab token rasmiy imo-ishora imo-ishora jumlasiga lugʻati bilan solishtiriladi. Agar u lugʻatda mavjud boʻlsa, bevosita natijaviy imo-ishora jumlasiga sifatida qabul qilinadi. Agar token lugʻatda topilmasa, sinonimlar va soʻz birikmalari bazasi orqali mos variant izlanadi. Bunda tabiiy tildagi turli ifoda shakllarini standart imo-ishora jumlasiga keltirishga harakat qilinadi. Agar bu tekshiruv ham yetarli natija bermasa, SBERT modeli yordamida token va mavjud imo-ishora jumlasilar orasidagi semantik yaqinlik baholanadi [5].

Taklif etilgan algoritmning asosiy vazifasi tabiiy tildagi tokenlarni imo-ishora tilining standart imo-ishora jumlasiga birliklariga moslashtirishdan iborat. Kiruvchi token avvalo imo-ishora soʻzlari lugʻati bilan solishtiriladi. Agar token ushbu lugʻatda mavjud boʻlsa, u qoʻshimcha tekshiruvsiz mos imo-ishora jumlasiga sifatida qabul qilinadi. Bu holat eng ishonchli natija hisoblanadi, chunki token rasmiy lugʻatdagi mavjud birlik bilan toʻgʻridan-toʻgʻri mos keladi.

Mazkur jarayon quyidagicha ifodalanadi:

$$x_i \in G$$

Bu yerda x_i kiruvchi tokenni, G esa standart imo-ishora imo-ishora jumlasilari lugʻatini bildiradi. Agar token lugʻatda mavjud boʻlsa, natijaviy imo-ishora jumlasiga quyidagicha belgilanadi:

$$g_i = x_i$$

Biroq real matnlarda tokenlar har doim ham lugʻatdagi shakl bilan aynan mos kelmaydi. Ular qoʻshimchalar bilan kelishi, sinonim shaklda ishlatilishi yoki murakkab birikma tarkibida boʻlishi mumkin. Shuning uchun algoritm faqat toʻgʻridan-toʻgʻri lugʻat qidiruvi bilan cheklanmaydi. Agar token lugʻatda topilmasa, sinonimlar va soʻz birikmalari bazasi ishga tushiriladi. Bu baza tabiiy tildagi turli ifoda shakllarini standart imo-ishora jumlasiga shakllari bilan bogʻlash uchun xizmat qiladi [8].

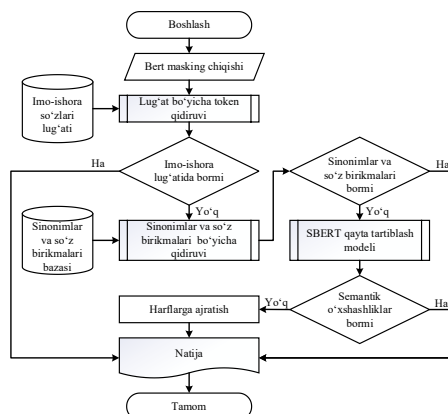
Masalan, matnda ishlatilgan soʻz imo-ishora jumlasiga lugʻatida mavjud boʻlmasligi mumkin, ammo uning maʼnodosh shakli yoki unga yaqin birikma lugʻatda boʻlishi ehtimoli mavjud. Bunday holatda token sinonimlar bazasi orqali standart imo-ishora jumlasiga keltiriladi. Ushbu jarayon umumiy koʻrinishda quyidagicha ifodalanadi:

$$x_i \notin G \Rightarrow Syn(x_i)$$

Bu yerda $Syn(x_i)$ token uchun sinonimlar va mos soʻz birikmalari toʻplamini bildiradi. Agar ushbu toʻplamdagi birliklardan biri imo-ishora jumlasiga lugʻatida mavjud boʻlsa, u natijaviy imo-ishora jumlasiga sifatida tanlanadi:

$$g_i = match(Syn(x_i), G)$$

Sinonimlar va soʻz birikmalari asosidagi qidiruv algoritmning moslashuvchanligini oshiradi. Chunki foydalanuvchi matnida bir xil maʼno turli soʻzlar orqali berilishi mumkin. Algoritmi esa bunday farqlarni inobatga olib, 1-rasmda berilganidek tokenni standart imo-ishora jumlasiga keltirishga harakat qiladi. Natijada tarjima jarayonida soʻzlarning tushib qolishi yoki notoʻgʻri ifodalanishi kamayadi [1], [8].



1-rasm. Imo-ishora jumlasilarni lugʻatga moslashtirish va cheklash algoritmi blok-sxemasini.

Ayrim hollarda token na standart imo-ishora jumlasini lug'atida, na sinonimlar va so'z birikmalari bazasida aniqlanadi. Bunday vaziyatda SBERT asosidagi semantik qayta tartiblash modeli qo'llanadi. SBERT modeli token va imo-ishora jumlasini vektorli fazoda ifodalab, ular orasidagi mazmuniy yaqinlikni aniqlash imkonini beradi [5]. Bu yondashuv oddiy satrlar o'xshashligiga emas, balki token va imo-ishora jumlasining semantik mazmuniga asoslanadi.

Semantik o'xshashlik quyidagicha aniqlanadi:

$$\text{sim}(t, g) = \cos(E_t, E_g)$$

Bu yerda E_t tokenning kontekstual vektorini, E_g esa imo-ishora jumlasining vektorli ifodasini bildiradi. Kosinus o'xshashlik qiymati token va imo-ishora jumlasini orasidagi mazmuniy yaqinlik darajasini ko'rsatadi. Bunday vektorli semantik ifodalash yondashuvi BERT va SBERT modellarining kontekstual embedding imkoniyatlariga asoslanadi [4].

Algoritm barcha mavjud imo-ishora jumlasini orasidan token bilan eng yaqin semantik bog'liqlikka ega birlikni tanlaydi:

$$g^* = \arg \max_{g \in G} \text{sim}(t, g)$$

Agar maksimal o'xshashlik qiymati oldindan belgilangan chegaradan yuqori bo'lsa, tanlangan imo-ishora jumlasini natijaviy birlik sifatida qabul qilinadi:

$$\text{sim}(t, g^*) \geq \theta$$

Bu yerda θ semantik moslik chegarasini bildiradi. Agar o'xshashlik qiymati ushbu chegaradan past bo'lsa, token ishonchsiz deb baholanadi. Bunday holatda algoritm tokenni noto'g'ri imo-ishora jumlasini bilan almashtirmaydi, balki uni harflarga ajratish orqali ifodalashga o'tkazadi. Bu yondashuv, ayniqsa, atoqli otlar, qisqartmalar, yangi terminlar yoki imo-ishora jumlasini lug'atida mavjud bo'lmagan maxsus birliklar uchun muhim hisoblanadi [6].

Harflarga ajratish quyidagicha ifodalanadi:

$$x_i \rightarrow \{h_1, h_2, \dots, h_n\}$$

Bu yerda $h_1, h_2, \dots, h_n$ token tarkibidagi harflar ketma-ketligini bildiradi. Ushbu mexanizm orqali noma'lum token tarjima jarayonidan butunlay chiqarib tashlanmaydi. Aksincha, u harfma-harf ifodalanib, tarjima uzluksizligi saqlab qolinadi.

Algoritm yakunida har bir token uchun tanlangan mos birliklar umumlashtiriladi va natijaviy imo-ishora jumlasini ketma-ketligi shakllantiriladi:

$$G' = \{g_1, g_2, \dots, g_n\}$$

Bu yerda G' moslashtirilgan imo-ishora jumlasini majmuasini, g_i esa har bir token uchun tanlangan natijaviy imo-ishora jumlasini bildiradi. Ushbu imo-ishora jumlasini keyingi bosqichda imo-ishora animatsiyasi yoki avatar harakatlarini hosil qiluvchi modulga uzatiladi. Natijaviy imo-ishora jumlasini standart lug'at bilan mos, semantik jihatdan asoslangan va animatsiya moduli uchun qulay shaklda bo'lishi kerak [2], [3].

Taklif etilgan algoritmnin afzalligi shundaki, u tokenlarni faqat bitta mezon asosida emas, balki lug'aviy, sinonimik va semantik tekshiruvlar asosida baholaydi. Dastlabki lug'at qidiruvi tezkor va aniq natija beradi. Sinonimlar va so'z birikmalari bazasi esa tabiiy tildagi turli ifoda shakllarini qamrab olish imkonini yaratadi. SBERT modeli esa aynan moslik topilmagan hollarda mazmuniy yaqin imo-ishora jumlasini tanlashga yordam beradi. Harflarga ajratish mexanizmi esa noma'lum birliklarni yo'qotmasdan ifodalash imkonini beradi.

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MURAKKAB FRAKTAL TUZILISHLI OBYEKT LARNI ANALITIK USULLAR YORDAMIDA VIZUALLASHTIRISH DASTURIY VOSITA VA INTERFEYSI

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“Fractal GeneratorUZ” dasturiy fositasi orqali ko’plab fraktal shakllarni yaratish mumkin. (1)-rasmda ishlab chiqilgan dasturiy majmuaning ishchi grafik interfeyslarining ko’rinishlari keltirilgan. Dasturiy vosita ishga tushirilganda namoyish bo’luvchi asosiy grafik interfeysning ko’rinishi (1)-rasmda keltirilgan. Bu asosiy grafik interfeys majmuani boshqarish uchun mo’ljallangan quyidagi menyularni o’z ichiga oladi:

“Fayl” menyusida yaratilgan fraktal shakllarni “PNG (.png)”, “EPS (.eps)”, “JPEG (.jpg, .jpeg)” formatlarda saqlash, dasturdan tugatish amallari bajariladi;

“Ishlov berish” menyusida fraktal shakllarga ishlov berish uchun fayl to’g’risidagi ma’lumotlarni ko’rsatish, fraktal shaklni nusxasini ko’chirish amallari bajariladi.

“Sozlamalar” menyusida Paskal uchburchagi asosidagi fraktal shakllarning ranglarini o’zgartirish imkonini beradi.

“Yordam” menyusida dasturiy vositadan qanday foydalanish va dastur haqida ma’lumotlarini olish amallari bajariladi.



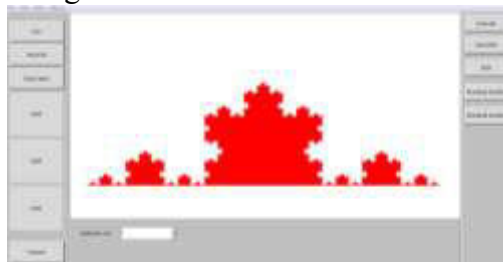
(1-rasm). Dasturiy vositaning asosiy ishchi oynasi.

Fraktallarni geometrik usul bilan qurish uchun “Geometrik” oynasini tanlaymiz. Fraktal shakllarni chizish uchun “oltiburchak”, “uchburchak” va “to’rtburchak” menyularidan foydalanishimiz kerak bo’ladi. Misol uchun “oltiburchak” menyusini tanlab “qadamlar soni” menyusida qadamlar sonini kiritganimizda bizga fraktal shaklni geometrik usul orqali chizib beradi. Biz (1)-rasmda ko’rishimiz mumkin.



(2)-rasm. Geometrik usul orqali chizish oynasi.

Murakkab tuzilishli fraktallarni RFM usuli yordamida chizish uchun “RFM” oynasini tanlaymiz. Unda biz (2)-rasmida tasvirlangan ishchi oynasini ko’rishimiz mumkin bo’ladi. Birinchi navbatda biz qanday fraktal shaklni chizishimiz kerakligini “Kox”, “Serpın uchburchagi” va “Serpın gilami” menyularini tanlash orqali amalga oshiramiz. “Qadamlar soni” menyusida qadamlar sonini kiritganimizda bizga fraktal shaklni RFM usulida chizish orqali chizib beradi.



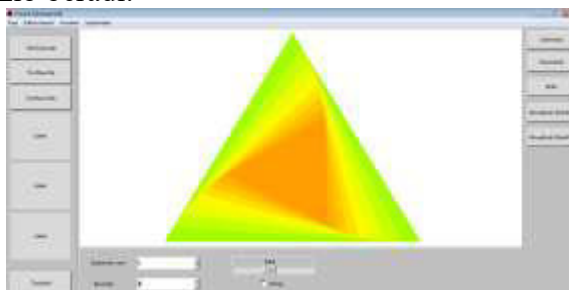
(3)-rasm. RFM usuli yordamida chizish oynasi.

Fraktallarni arifmetik xususiyatli binomial ko’phadlar usulida chizish uchun “Arifmetik” oynasini tanlaymiz. Paskal uchburchagi asosidagi fraktal shaklni chizishimiz uchun birinchi navbatda Paskal uchburchagi asosidagi elementlarini “oltiburchak”, “to’rtburchak” va “uchburchak” menyusi orqali chizishni tanlashimiz kerak. Undan so’ng Paskal uchburchagidagi ustunlar sonini “ustunlar soni” menyusi orqali kiritishimiz kerak. Dastur bizga berilgan ustunlar soni bo’yicha Paskal uchburchagini chizib beradi. Biz taklif qilayotgan Paskal uchburchagi asosidagi algebraik tuzilmalar va tub sonlar nazariyasi usulini hisobga olgan holda fraktal ko’rinishdagi tasvirlarni yaratish usul va algoritmnı amalga oshirish uchun “Mod” menyusidan tub sonlarni kiritishimiz kerak va u orqali dastur fraktal shaklni chizib beradi. Shu bilan birgalikda Paskal uchburchagi asosidagi fraktal shaklning ranglari sonini ko’rsatib beradi.



(4)-rasm. Fraktallarni arifmetik xususiyatli binomial ko’phadlar usulida chizish oynasi.

Tekislikdagi geometrik almashtirishlar asosida murakkab fraktal tuzilishdagi tasvirlarni yaratish uchun “Murakkab shakllar” oynasini tanlaymiz. Agar biz RFM-usuli yordamida murakkab fraktallarni yaratmoqchi bo’lsak “oltiburchak”, “to’rtburchak” va “uchburchak” menyularidan birini tanlab, qadamlar sonini kiritib, 2-qadamdagi shaklni burish burchagini kiritishimiz kerak. Shundan so’ng dastur fraktal shaklni chizib beradi.



(5)-rasm. Tekislikdagi geometrik almashtirishlar asosida murakkab fraktal tuzilishdagi tasvirlarni chizish oynasi.

Tekislikdagi geometrik almashtirishlar orqali Paskal uchburchagi asosida murakkab fraktalni vizuallashtirish uchun “Murakkab shakllar” oynasini tanlaymiz va fraktal shakllarni vizuallashtiramiz.

Fraktal shaklni vizuallashtirishdan oldin ranglarni tanlashimiz kerak bo'ladi. Rangni o'zgartirish uchun "Rang o'zgartirish" menyusi orqali kerakli rangni tanlash amali bajariladi. "Fractal GeneratorUZ" dasturi ikki o'lchovli fraktallarni hosil qilish uchun yaratildi.

TIBBIY MA'LUMOTLARNI TEZKOR UZATISH, XABAR BERISH HAMDA REAL VAQT REJIMIDA TAHLIL QILISH AXBOROT TIZIMINI ISHLAB CHIQISHNING MATEMATIK MODELI

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Annotatsiya. Maqolada tibbiy ma'lumotlarni tezkor uzatish, xabar berish va real vaqt rejimida tahlil qilish axborot tizimining uch bosqichli matematik modeli taklif etilgan. Ma'lumotlarni uzatish jarayoni M/M/c navbat tizimi sifatida, hayotiy ko'rsatkichlardagi anomalialar eksponensial vaznli siljivchi o'rtacha (EWMA) nazorat kartasi yordamida, bemor holatining o'zgarishi esa Markov zanjiri orqali modellashirilgan. Model tizimning kechikishini (latency) oldindan baholash, anomalialarni minimal kechikish bilan aniqlash hamda tibbiy resurslarni rejalashtirish imkonini beradi. Keltirilgan sonli misollar modelning amaliy qo'llanilishini ko'rsatadi.

Kalit so'zlar: matematik modellashirish, navbatlar nazariyasi, Erlang formulasi, Markov zanjiri, EWMA nazorat kartasi, real vaqt, tibbiy axborot tizimi, anomalialarni aniqlash.

Kirish

Zamonaviy sog'liqni saqlash tizimida bemorlarning hayotiy ko'rsatkichlarini (yurak urishi, qon bosimi, tana harorati, qondagi kislorod miqdori va boshqalar) uzluksiz kuzatib borish hamda ushbu ma'lumotlarni tibbiy xodimlarga tezkor yetkazish dolzarb vazifaga aylangan. IoT (Internet of Things) datchiklari va telemeditsina tizimlari katta hajmdagi ma'lumot oqimini hosil qiladi; bu ma'lumotlar real vaqt rejimida uzatilishi, qayta ishlanishi va tahlil qilinishi lozim. Bunday tizimning ishonchliligi va kechikishini oldindan baholash, shuningdek anomal holatlarni o'z vaqtida aniqlash uchun qat'iy matematik asos zarur.

Ushbu ishda tizimning uch bosqichli matematik modeli taklif etiladi: (1) ma'lumotlarni uzatish jarayonini navbatlar nazariyasi asosida modellashirish; (2) hayotiy ko'rsatkichlardagi anomalialarni EWMA nazorat kartasi yordamida aniqlash; (3) bemor holati dinamikasini Markov zanjiri orqali tavsiflash.

1. Ma'lumotlarni uzatishning navbat modeli

Datchiklardan markaziy serverga keluvchi ma'lumot paketlari oqimini Puasson jarayoni sifatida qaraymiz: paketlar λ intensivlik bilan keladi, har bir qayta ishlovchi tugun eksponensial taqsimot bo'yicha μ intensivlik bilan xizmat ko'rsatadi. Tizimda c ta parallel server mavjud bo'lsa, u M/M/c navbat tizimi sifatida modellashiriladi. Tizim yuklamasi:

$$\rho = \lambda / (c \cdot \mu) \quad (1)$$

Tizimning barqaror (statsionar) ishlashi uchun $\rho < 1$ sharti bajarilishi shart. Barcha serverlar band bo'lib, kelgan paketning navbatda kutish ehtimoli Erlang C formulasi bilan aniqlanadi:

$$P_{kut} = [(c\rho)^c / (c!(1 - \rho))] \cdot P_0 \quad (2)$$

bu yerda boshlang'ich (barcha serverlar bo'sh) holat ehtimoli:

$$P_0 = [\sum_{k=0}^{c-1} (c\rho)^k / k! + (c\rho)^c / (c!(1 - \rho))]^{-1} \quad (3)$$

Navbatda o'rtacha kutish vaqti:

$$W_q = P_{kut} / (c\mu - \lambda) \quad (4)$$

Paketning tizimda to'liq o'rtacha qolish vaqti $W = W_q + 1/\mu$, Little qonuniga ko'ra tizimdagi o'rtacha paketlar soni $L = \lambda W$.

Misol. $\lambda = 800$ paket/s, $\mu = 200$ paket/s va $c = 5$ bo'lsa, $\rho = 0,8$ (< 1 , barqaror), $P_{kut} \approx 0,554$, $W_q \approx 2,77$ ms, to'liq kechikish esa $W \approx 7,77$ ms ni tashkil etadi. Demak, model serverlar soni c ni shunday tanlash imkonini beradiki, kechikish tibbiy talab etilgan chegaradan (masalan, 10 ms) oshmaydi.

2. Anomaliyalarni real vaqt rejimida aniqlash (EWMA modeli)

Bemorning biror hayotiy ko'rsatkichi (masalan, yurak urishi) $x_1, x_2, \dots$ vaqt qatori sifatida kuzatiladi. Eksponensial vaznli siljuvchi o'rtacha (EWMA) statistikasi quyidagicha hisoblanadi:

$$z_t = \alpha x_t + (1 - \alpha)z_{t-1}, \quad 0 < \alpha \leq 1 \quad (5)$$

boshlang'ich qiymat $z_0 = \mu_0$ (normal holatdagi o'rtacha qiymat). Statistikaning dispersiyasi:

$$\text{Var}(z_t) = \sigma^2 \cdot (\alpha/(2 - \alpha)) \cdot [1 - (1 - \alpha)^{2t}] \quad (6)$$

$t \rightarrow \infty$ da asimptotik chegaraviy og'ish $\sigma_z = \sigma\sqrt{\alpha/(2 - \alpha)}$. Nazorat chegaralari quyidagicha aniqlanadi:

$$\text{UCL/LCL} = \mu_0 \pm L\sigma\sqrt{\alpha/(2 - \alpha)} \quad (7)$$

bu yerda L — sezgirlik koeffitsiyenti (odatda $L \approx 2,7-3,0$). Agar z_t ushbu chegaradan chiqsa, tizim anomaliya (xavfli holat) haqida avtomatik signal beradi. Parametr α kichik bo'lsa, model sekin lekin shovqinga barqaror; katta bo'lsa, tez lekin shovqinga sezgir bo'ladi. Shu sababli α va L har bir tibbiy ko'rsatkich xususiyatiga qarab sozlanadi.

3. Bemor holatining Markov modeli

Bemor holatini uchta diskret holatga ega $S = \{N — \text{normal}, W — \text{ogohlantirish}, C — \text{kritik}\}$ Markov zanjiri sifatida modellashiramiz. Holatlararo o'tish ehtimollari P matritsasi bilan beriladi. Namuna sifatida quyidagi matritsa qaraladi:

P	N	W	C
N	0,90	0,08	0,02
W	0,30	0,55	0,15
C	0,50	0,30	0,20

Statsionar taqsimot $\pi = (\pi_N, \pi_W, \pi_C)$ $\pi P = \pi$ va $\sum \pi_i = 1$ tenglamalar tizimidan topiladi. Keltirilgan matritsa uchun $\pi \approx (0,776; 0,172; 0,052)$. Bu shuni anglatadiki, uzoq muddatda bemor vaqtining taxminan 5,2 % qismi kritik holatga to'g'ri keladi — ushbu ko'rsatkich tibbiy resurslarni (hamshira, monitoring quvvati) rejalashtirishda asos bo'ladi.

Normal holatdan kritik holatga birinchi marta o'tishning kutilayotgan vaqti (first passage time) quyidagi tizimdan aniqlanadi:

$$m_i = 1 + \sum_{j \neq C} p_{ij}m_j, \quad m_C = 0 \quad (8)$$

Keltirilgan misol uchun $m_N \approx 25,24$ o'lchov oralig'ini tashkil etadi. Agar har bir o'lchov 1 daqiqada olinsa, bemor o'rtacha taxminan 25 daqiqada normal holatdan kritik holatga o'tishi mumkin; bu esa profilaktik chora-tadbir ko'rish uchun “vaqt oynasi”ni belgilaydi.

Xulosa

Taklif etilgan uch bosqichli matematik model tibbiy ma'lumotlarni tezkor uzatish, xabar berish va real vaqtda tahlil qilish tizimini loyihalashda quyidagi amaliy imkoniyatlarni beradi: navbatlar nazariyasi serverlar sonini va kechikishni oldindan hisoblab, real vaqt talablarini kafolatlash imkonini beradi; EWMA modeli minimal kechikish bilan anomaliyalarni aniqlaydi; Markov zanjiri esa bemor holati dinamikasini bashorat qilish va resurslarni rejalashtirishga xizmat qiladi. Kelgusi tadqiqotlarda model real klinik ma'lumotlar asosida validatsiya qilinib, mashinali o'rganish usullari (xususan, LSTM kabi neyron tarmoqlar) bilan integratsiyalanishi mo'ljallangan.

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РАЗРАБОТКА ЧИСЛЕННОГО МЕТОДА ВОССТАНОВЛЕНИЯ ФУНКЦИЙ ПО ИНТЕГРАЛАМ НА ПАРАБОЛИЧЕСКИХ КРИВЫХ

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Аннотация. Обратные задачи интегральной геометрии занимают важное место в современной прикладной математике и находят широкое применение в компьютерной томографии, обработке изображений, геофизике, медицинской диагностике и задачах дистанционного зондирования. Одним из центральных направлений данной области является восстановление функций по интегральным данным, полученным на определённых семействах кривых или поверхностей. Классическим примером подобного подхода является преобразование Радона[1], теория которого получила широкое развитие и стала фундаментальной основой современных методов томографической реконструкции.

В последние годы особый интерес исследователей вызывают задачи восстановления функций на неклассических семействах кривых. Это обусловлено как необходимостью моделирования сложных физических процессов, так и развитием новых методов интегральной геометрии. В отличие от прямолинейных траекторий, параболические кривые позволяют описывать более широкий класс процессов распространения сигналов и взаимодействия волн в неоднородных средах. В связи с этим исследование обратных задач на параболических семействах кривых представляет как теоретический, так и практический интерес..

В данной работе рассматривается задача восстановления функции по интегралам на семействе кривых, задаваемых уравнением [2]

$$(y - \eta)^2 = |x - \xi|,$$

которые представляют собой параболические траектории. Такие кривые возникают, например, при моделировании процессов распространения сигналов и в задачах нетрадиционной томографии.

Для исследования поставленной задачи использован аппарат интегральных преобразований и методов функционального анализа. Получено аналитическое представление решения с применением двумерного преобразования Фурье. Проведён анализ свойств рассматриваемого интегрального оператора, а также доказана единственность решения в классе гладких функций с компактным носителем. Полученные результаты позволяют обосновать корректность предложенного подхода и определить условия существования решения.

Особое внимание уделено разработке численного алгоритма восстановления функции. Для стабилизации вычислительного процесса применён метод регуляризации Тихонова, обеспечивающий устойчивость решения при наличии шумов в экспериментальных данных. Регуляризационный подход позволяет существенно снизить влияние ошибок измерений и повысить точность реконструкции. Разработанный алгоритм реализован в вычислительной среде и протестирован на модельных примерах.

Проведённые численные эксперименты продемонстрировали эффективность предложенного метода восстановления. Полученные результаты показывают устойчивость алгоритма к случайным шумовым возмущениям и подтверждают возможность практического применения разработанного подхода в задачах нетрадиционной томографии и обработки изображений. Сравнительный анализ численных результатов свидетельствует о достаточной точности реконструкции и стабильности вычислительного процесса.

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ZARAFSHON DARYOSI OQIMINING MAVSUMIY VA YILLIK O'ZGARUVCHANLIGINI SONLI USULLAR YORDAMIDA MODELASHTIRISH

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Annotatsiya. Ushbu maqolada Zarafshon daryosining Ravotxo'ja to'g'oni gidrologik stansiyasida 2015–2025 yillar davomida to'langan dekadal sarflik ma'lumotlari asosida noturg'un oqimning matematik modeli qurilgan va sonli yechimlar olingan. Bir o'lchovli Sen-Venan qisman differensial tenglamalari tizimi Preissmann to'rt nuqtali implitsit sxemasi ($\theta=0.6$) yordamida yechildi.

Keyingi o'n yillikda global iqlim o'zgarishi va ortib borayotgan suv iste'moli fonida Markaziy Osiyo daryolarida oqim miqdorining sezilarli kamayishi kuzatilmoqda. Zarafshon daryosida ham 2018, 2020 va ayniqsa 2021-yillarda qayd etilgan past oqim davrlari mintaqaviy suv tanqisligi muammosini yanada keskinlashtirdi. Shuning uchun daryodagi oqimning yillik va mavsumiy o'zgaruvchanligini aniq modelashtirish va kelajakdagi rejimni baholash ilmiy va amaliy jihatdan muhim ahamiyatga ega [1, 2].

Ochiq kanal gidravlikasida noturg'un oqimni tahlil qilishning asosiy matematik apparati Sen-Venan tenglamalari hisoblanadi. Bu tenglamalar massa va impuls saqlanish qonunlarini ifodalaydigan qisman differensial tenglamalar tizimidan iborat bo'lib, kanallar va daryolardagi vaqt bo'yicha o'zgaruvchan oqimni to'liq tavsiflaydi [3]. Ushbu tenglamalarning analitik yechimi cheklangan holatlarda mavjud bo'lganligi sababli, amaliy masalalarda raqamli usullardan, xususan Preissmann implitsit sxemasidan keng foydalaniladi [4,5].

Ushbu maqolaning asosiy maqsadi - Zarafshon daryosining Ravotxo'ja to'g'oni gidrologik stansiyasida 2015–2025 yillar davomida o'lchangan dekadal sarflik ma'lumotlari asosida: yillik oqim o'zgaruvchanligini statistik tahlil qilish; mavsumiy taqsimotni aniqlash; noturg'un oqimni Sen-Venan tenglamalari yordamida modelashtirish; Mann-Kendall trend testini qo'llash orqali oqim tendensiyasini baholashdan iborat.

Ochiq kanal yoki daryodagi bir o'lchovli noturg'un oqim Sen-Venan qisman differensial tenglamalar tizimi bilan tavsiflanadi [1, 2]. Ushbu tizim ikkita asosiy tenglamadan iborat:

Massa saqlanish qonuni (davomiylik tenglamasi):

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_L \quad (1)$$

Impuls saqlanish qonuni (harakat miqdori tenglamasi):

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left(\frac{Q^2}{A} \right) + gA \left(\frac{\partial h}{\partial x} + S_f - S_0 \right) = 0 \quad (2)$$

Bu tenglamalarda: $\partial A / \partial t$ — oqim yuzasining vaqt bo'yicha o'zgarishi; A — ko'ndalang kesim yuzasi (m^2); Q — sarflik (m^3/s); x — uzunlik koordinatasi (m); t — vaqt (s); q_L — lateral oqim (m^2/s); $g = 9.81 \text{ m/s}^2$; h — suv chuqurligi (m); S_0 — kanal tubi qiyaligi; S_e — ishqalanish qiyaligi.

Ishqalanish qiyaligi Manning formulasi orqali hisoblanadi:

$$S_f = \frac{n^2 Q^2}{A^2 \cdot R^3} \quad (3)$$

Bu yerda: n — Manning qo'pnaklik koeffitsienti (Zarafshon uchun $n = 0.032\text{--}0.040$); $R = A/P$ — gidravlik radius (m); P — ho'llangan perimetr (m). Keng to'rtburchak kanalda ($B \gg h$) bu formula quyidagi ko'rinishda yoziladi:

$$S_f = \frac{n^2 Q^2}{B^2 \cdot h^{\frac{10}{3}}} \quad (4)$$

Yuqori chegaraviy shart ($x = 0$): kirish kesimida sarflik gidrogrammasi $Q(0, t)$ kuzatilgan ma'lumotlardan chiziqli interpolatsiya yordamida berildi.

Quyi chegaraviy shart ($x = L$): chiqish kesimida normal chuqurlik doimiy deb qabul qilindi:

$$h(L, t) = h_n = \text{const}, \left. \frac{\partial h}{\partial x} \right|_{x=L} = 0 \quad (5)$$

Normal chuqurlik Manning tenglamasidan iterativ yo'l bilan topiladi:

$$h_n = \left(\frac{Q \cdot n}{B \cdot S_0^{\frac{1}{2}}} \right)^{\frac{3}{5}} \quad (6)$$

Boshlang'ich shart ($t = 0$) — barqaror oqim rejimi:

$$\frac{\partial Q}{\partial t} = 0, \frac{\partial h}{\partial t} = 0 \Rightarrow \text{Barqaror } Q_0(x), h_0(x) \quad (7)$$

Asosiy statistik ko'rsatkichlar quyidagicha:

Ko'p yillik o'rtacha yillik oqim:

$$Q = \frac{1}{N} \cdot \sum_{i=1}^N Q_i \quad (8)$$

Dispersiya va standart og'ish:

$$\sigma^2 = \frac{1}{N} \cdot \sum_{i=1}^N (Q_i - Q)^2, \sigma = \sqrt{\sigma^2} \quad (9)$$

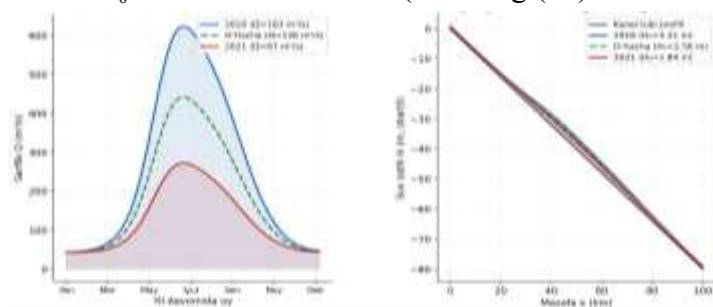
Variatsiya koeffitsiyenti:

$$CV = \frac{\sigma}{Q} \times 100\% \quad (10)$$

Zarafshon uchun: $\bar{Q} = 3969.95 \text{ mln } m^3$; $\sigma = 701.60 \text{ mln } m^3$; $CV = 17.67\%$.

Noturg'un oqimning sonli modellashtirish natijalari quyidagicha: 1-rasmda Sen-Venan tenglamalarining Preissmann sxemasi ($\theta = 0.6, \Delta t = 600 \text{ s}, \Delta x = 1000 \text{ m}$) yordamida yechilishi natijalari 2016, 2021 va ko'p yillik o'rtacha uchun ko'rsatilgan.

1a-rasm — $Q(t)$ gidrogrammasi: 2016-yilda iyul cho'qqisida $Q_{maks} = 488 m^3 / s$, 2021-yilda $197 m^3 / s$ — 2.5 martadan ko'proq farq. 1b-rasm — $H(x)$ suv sathi profili: 2016 da $h_0 = 3.20 \text{ m}$, o'rtacha $h_0 = 2.71 \text{ m}$, 2021 da $h_0 = 2.12 \text{ m}$ ($h_0 = 2.12 \text{ m}$ (Manning (10)-formulasi).



1-rasm. Sen-Venan / Preissmann modeli natijalari: (a) $Q(t)$ sarflik gidrogrammasi; (b) $H(x)$ suv sathi uzunlik profili (iyul oyi, maksimal sarflik).

Olingan natijalar Navoiy viloyatining sug'orish tizimini rivojlantirish va to'g'on operations boshqaruvini yaxshilash uchun muhim amaliy asos yaratadi.

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DYNAMICS OF COMPOSITIONS OF LOTKA–VOLTERRA TYPE QUADRATIC OPERATORS CORRESPONDING TO TOURNAMENTS DEFINED ON A THREE-DIMENSIONAL SIMPLEX

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Key words: Quadratic Lotka – Volterra mapping, simplex, mixed tournament, Jacobian, fixed point, repeller, attractor

Annotation: This article is entitled “Dynamics of Compositions of Lotka–Volterra Type Quadratic Operators Corresponding to Tournaments Defined on the Three-Dimensional Simplex.” In this study, the dynamics of compositions of four Lotka–Volterra type quadratic operators corresponding to tournaments defined on the three-dimensional simplex are thoroughly investigated. The fixed points are determined, their qualitative characteristics are analyzed, and the limit points of the trajectories are identified.

The main part: In the development of mathematical biology in Uzbekistan, the application of probabilistic methods to the study of dynamical systems was first initiated by Academician T.A. Sarimsakov. The further development of the theory of quadratic stochastic Lotka–Volterra operators, through the application of graph theory and the qualitative theory of differential equations to problems in mathematical biology, can be observed in the scientific works of R.N. Ganikhodjaev, K.A. Kurganov, and D.B. Eshmatova.

The set

$$S^{m-1} = \left\{ x = (x_1, x_2, \dots, x_m) \in R^m, x_i \geq 0, \sum_{i=1}^m x_i = 1 \right\}$$

is called the $m-1$ dimensional simplex [1]. A mapping $V: S^{m-1} \rightarrow S^{m-1}$ defined on the $m-1$ dimensional simplex by

$$V: x'_k = \sum_{i,j=1}^m P_{ij,k} x_i x_j, \quad k = \overline{1, m} \quad (1)$$

is called a **quadratic stochastic operator** (QSO). Here $P_{ij,k} \geq 0, P_{ij,k} = P_{ji,k}, \sum_{k=1}^m P_{ij,k} = 1$ [1].

Definition 1. For the operator $V: S^{m-1} \rightarrow S^{m-1}$ defined by (1), if, $k \notin \{i, j\}$ for $P_{ij,k} = 0$ then the operator (1) is called a Lotka–Volterra type quadratic stochastic operator.

Theorem 1 [1]. A Lotka–Volterra type quadratic stochastic operator can be written in the following form:

$$V : x'_k = x_k \left(1 + \sum_{i=1}^m a_{ki} x_i \right) \quad (2)$$

where $a_{ki} = 2P_{ik,k} - 1$, $i \neq k$, $a_{kk} = 0$, $a_{ik} = -a_{ki}$, $i, k = \overline{1, m}$, $|a_{ki}| < 1$.

Definition 2 [2]. A point x satisfying the equality $V(x) = x$ called a **fixed point** of the operator V . The set of fixed points of V is denoted by $FixV = \{x \in S^{m-1} : V(x) = x\}$.

Aytaylik $x^0 \in S^{m-1}$, $x^0 \neq Fix(x)$. nuqta bo'lsin.

Definition 3 [2]. For a given $x^0 \in S^{m-1}$ the sequence, $\{x^0, x^{(1)}, \dots, x^{(n)}, \dots\}$ is called the trajectory starting from the point x^0 , where $x^{(n)} = V(\dots(Vx^0)\dots) = Vx^{(n-1)}$.

The fixed points of a Lotka–Volterra operator may possess the following topological characteristics: attracting, repelling, and saddle.

Let the following Lotka–Volterra type quadratic operators be given.

$$V_1 : x'_k = x_k \left(1 + \sum_{i=1}^m a_{ki} x_i \right), \text{ and } V_2 : x'_k = x_k \left(1 + \sum_{i=1}^m b_{ki} x_i \right), k = \overline{1, m}$$

$(V_1 \circ V_2)(x) = V_1(V_2(x))$ or $(V_2 \circ V_1)(x) = V_2(V_1(x))$ define a composite operator, which is called the composition of the operators V_1 and V_2 .

Proof 1 [3]. The composition of the operators V_1 and V_2 can be expressed in the following form:

$$V_1 \circ V_2 : x'_k = x_k (1 + f_k(x_1, x_2, \dots, x_{k-1}, x_{k+1}, \dots, x_m)), k = \overline{1, m}$$

Let the composition operator $W_* = V_i \circ V_j : S^{m-1} \rightarrow S^{m-1}$ be given.

Assume that in S^3 there are tournaments differing by two edges, as shown in Figure 1

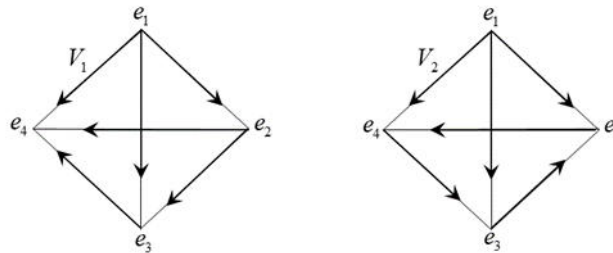


Figure 1. Tournaments in S^3 that differ by two edges.

The Lotka–Volterra type quadratic operators corresponding to these tournaments have the following form:

$$V_1 : \begin{cases} x'_1 = x_1 (1 - a_{12}x_2 - a_{13}x_3 - a_{14}x_4), \\ x'_2 = x_2 (1 + a_{12}x_1 - a_{23}x_3 - a_{24}x_4), \\ x'_3 = x_3 (1 + a_{13}x_1 + a_{23}x_2 - a_{34}x_4), \\ x'_4 = x_4 (1 + a_{14}x_1 + a_{24}x_2 + a_{34}x_3), \end{cases} \quad V_2 : \begin{cases} x'_1 = x_1 (1 - a_{12}x_2 - a_{13}x_3 - a_{14}x_4), \\ x'_2 = x_2 (1 + a_{12}x_1 + a_{23}x_3 - a_{24}x_4), \\ x'_3 = x_3 (1 + a_{13}x_1 - a_{23}x_2 + a_{34}x_4), \\ x'_4 = x_4 (1 + a_{14}x_1 + a_{24}x_2 - a_{34}x_3), \end{cases} \quad (3)$$

Here $0 \leq a_{ki} \leq 1$, $k, i = \overline{1, 4}$, $k \neq i$.

The composition of these operators can be determined as follows:

$$V_1 \circ V_2 : \begin{cases} x'_1 = x_1 (1 - a_{12}x_2 - a_{13}x_3 - a_{14}x_4)(1 - a_{12}x_2(1 + a_{12}x_1 + a_{23}x_3 - a_{24}x_4) - \\ - a_{13}x_3(1 + a_{13}x_1 - a_{23}x_2 + a_{34}x_4) - a_{14}x_4(1 + a_{14}x_1 + a_{24}x_2 - a_{34}x_3)), \\ x'_2 = x_2(1 + a_{12}x_1 + a_{23}x_3 - a_{24}x_4)(1 + a_{12}x_1(1 - a_{12}x_2 - a_{13}x_3 - a_{14}x_4) - \\ - a_{23}x_3(1 + a_{13}x_1 - a_{23}x_2 + a_{34}x_4) - a_{24}x_4(1 + a_{14}x_1 + a_{24}x_2 - a_{34}x_3)), \\ x'_3 = x_3(1 + a_{13}x_1 - a_{23}x_2 + a_{34}x_4)(1 + a_{13}x_1(1 - a_{12}x_2 - a_{13}x_3 - a_{14}x_4) + \\ + a_{23}x_2(1 + a_{12}x_1 + a_{23}x_3 - a_{24}x_4) - a_{34}x_4(1 + a_{14}x_1 + a_{24}x_2 - a_{34}x_3)), \\ x'_4 = x_4(1 + a_{14}x_1 + a_{24}x_2 - a_{34}x_3)(1 + a_{14}x_1(1 - a_{12}x_2 - a_{13}x_3 - a_{14}x_4) + \\ + a_{24}x_2(1 + a_{12}x_1 + a_{23}x_3 - a_{24}x_4) + a_{34}x_3(1 + a_{13}x_1 - a_{23}x_2 + a_{34}x_4)), \end{cases} \quad (4)$$

Lemma 1. For the composition operators $V_1 \circ V_2$ and $V_2 \circ V_1$, the following statements hold:

i) The operators $V_1 \circ V_2$ and $V_2 \circ V_1$ have six fixed points, which are located at the vertices of the simplex and on the edges $\Gamma_{e_2e_3}$ and $\Gamma_{e_3e_4}$.

ii) For every point $\forall y \in U_\varepsilon(e_3)$ in a sufficiently small neighborhood $\varepsilon > 0$ of the point e_3 the equality

$\lim_{n \rightarrow \infty} (V_i \circ V_j)^n(y) = e_3$ holds. Similarly, for every point $\forall x \in U_\delta(e_4)$ in a sufficiently small neighborhood $\delta > 0$ of the point e_4 the equality $\lim_{n \rightarrow \infty} (V_i \circ V_j)^n(x) = e_4$ holds.

iii) For every point $\forall x \in U_\delta(e_1)$ the relation $\lim_{n \rightarrow \infty} (V_i \circ V_j)^n(x) \neq e_1$ holds.

iv) The composition operator $V_i \circ V_j$ has a fixed point on the edge $\Gamma_{e_2e_3}$. If this point for $V_i \circ V_j$ is $O_1(0; \alpha; \beta; 0)$ then for $V_j \circ V_i$ it is $O_1(0; \beta; \alpha; 0)$. The same property holds for the fixed point located on the edge $\Gamma_{e_3e_4}$.

v) The fixed points of the composition operator $V_i \circ V_j$ located on the edges $\Gamma_{e_2e_3}$, $\Gamma_{e_3e_4}$ as well as the vertex e_2 are saddle points. Here $i, j = \overline{1, 2}$, $i \neq j$

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AN EFFICIENT PIECEWISE CONSTANT ARGUMENT APPROACH FOR CAPUTO-TYPE FRACTIONAL DIFFERENTIAL EQUATIONS.

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In this work, we provide numerical results obtained via the piecewise constant argument method for a fractional differential equation involving the Caputo derivative of the form

$$\begin{aligned} D_{0,t}^a y(t) &= f(t, y(t)), \\ y^{(k)}(0) &= y_0^{(k)}, \quad k = 0, 1, \dots, [a] - 1, \end{aligned} \quad (1)$$

the Caputo derivative $D_{0,t}^a y(t)$ of $y(t)$ is defined as

$$D_{0,t}^a y(t) = \frac{1}{\Gamma(n-a)} \int_0^t (t-\tau)^{n-a-1} y^{(n)}(\tau) d\tau, \quad n-1 < a < n \in \mathbb{Z}^+, \quad (2)$$

where $[a]=n$. It is well known that the initial value problem (1) is equivalent to the Volterra integral equation is given by [4]

$$y(t) = \sum_{k=0}^{n-1} \frac{y^{(k)}(0)}{k!} t^k + \frac{1}{\Gamma(a)} \int_0^t (t-\tau)^{a-1} f(\tau, y(\tau)) d\tau \quad (3)$$

We introduce the following function $y_n(t)$ at $t \in [\frac{k}{n}, \frac{k+1}{n}]$ depending on an arbitrary positive integer n

$$\begin{aligned} y_n(t) &= \sum_{k=0}^{n-1} \frac{y^{(k)}(0)}{k!} t^k + \frac{1}{\Gamma(a)} \int_0^t (t-\tau)^{a-1} f(t) \\ &+ \frac{1}{\Gamma(a)} \left(\sum_{k=0}^{n-1} \int_{\frac{k}{n}}^{\frac{k+1}{n}} (t-\tau)^{a-1} y\left(\frac{k}{n}\right) d\tau, \quad t \in \left[\frac{k}{n}, \frac{k+1}{n}\right] \right) \end{aligned} \quad (4)$$

where $y(\frac{k}{n}) = \lim_{t \rightarrow \frac{k}{n}} y(t)$, $y'(\frac{k}{n}) = \lim_{t \rightarrow \frac{k}{n}} y'(t)$, $k = 0, \dots, n-1$.

Problem 1. Consider the FDE given in [1], [2]

$$D_{0,t}^a y(t) = \frac{\Gamma(2a+1)}{\Gamma(a+1)} t^a - \frac{2}{\Gamma(3-a)} t^{2-a} + (t^{2a} - t^2)^4 - y^4(t), \quad y(0) = 0.$$

The exact solution of this problem is $y(t) = t^{2a} - t^2$.

t	$\alpha = 0.30$ FEAM3 $h = 10^{-3}$	$\alpha = 0.30$ PCAM $h = 10^{-3}$	$\alpha = 0.50$ FEAM3 $h = 10^{-3}$	$\alpha = 0.50$ PCAM $h = 10^{-3}$	$\alpha = 0.90$ FEAM3 $h = 10^{-3}$	$\alpha = 0.90$ PCAM $h = 10^{-3}$
0.1	1.4849×10^{-2}	3.1719×10^{-7}	9.0000×10^{-4}	2.1820×10^{-7}	2.9811×10^{-5}	1.0000×10^{-11}
0.2	6.3986×10^{-3}	2.0601×10^{-6}	4.9629×10^{-4}	1.4003×10^{-6}	2.4031×10^{-5}	1.0000×10^{-11}
0.3	1.3939×10^{-2}	6.1528×10^{-6}	8.9975×10^{-4}	2.6692×10^{-6}	3.4758×10^{-5}	7.2167×10^{-11}
0.4	1.4322×10^{-2}	1.3369×10^{-5}	9.4321×10^{-4}	5.5724×10^{-7}	3.6749×10^{-5}	6.6461×10^{-10}
0.5	1.4512×10^{-2}	2.4402×10^{-5}	9.6502×10^{-4}	1.3711×10^{-6}	3.7973×10^{-5}	1.2000×10^{-9}
0.6	1.4736×10^{-2}	3.9890×10^{-5}	9.8398×10^{-4}	2.0261×10^{-6}	3.9062×10^{-5}	1.2000×10^{-9}
0.7	1.5078×10^{-2}	6.0429×10^{-5}	1.0060×10^{-3}	1.4624×10^{-6}	4.0196×10^{-5}	7.0000×10^{-10}
0.8	1.5508×10^{-2}	8.6580×10^{-5}	1.0322×10^{-3}	2.3717×10^{-6}	4.1447×10^{-5}	5.0000×10^{-10}
0.9	1.5946×10^{-2}	1.1887×10^{-4}	1.0613×10^{-3}	4.0122×10^{-6}	4.2842×10^{-5}	8.0000×10^{-10}
1.0	1.6321×10^{-2}	1.5783×10^{-4}	1.0907×10^{-3}	6.4184×10^{-6}	4.4381×10^{-5}	7.2821×10^{-10}

Table 1: Absolute error at each point t when solving Problem 1 using FEAM3 and Piecewise constant arguments method (PCAM) for different step sizes h and $0 < \alpha < 1$

Methods	$\alpha = 0.2$	$\alpha = 0.4$	$\alpha = 0.6$	$\alpha = 0.8$
[2]	1.5115×10^{-4}	1.1413×10^{-4}	4.7817×10^{-5}	1.4556×10^{-5}
[3]	3.8120×10^{-5}	1.8891×10^{-4}	1.0385×10^{-4}	4.5617×10^{-4}
[4]	2.2944×10^{-4}	1.8812×10^{-4}	1.0385×10^{-4}	4.5617×10^{-4}
PCAM	8.8614×10^{-5}	2.4449×10^{-5}	2.29109×10^{-6}	4.6219×10^{-8}

Table 2: Absolute error at $t = 1$ when solving Problem 1 using [2], Daftardar-Gejji et al. [3], the fractional Adams scheme [4] and PCAM for $h = 0.01$ and $0 < \alpha < 1$

Problem 2. Consider the FDE given in [1], [2]

$$D_{0,t}^a y(t) = \frac{\Gamma(6)}{\Gamma(6-a)} t^{5-a} - \frac{3\Gamma(5)}{\Gamma(5-a)} t^{4-a} + \frac{2\Gamma(4)}{\Gamma(4-a)} t^{3-a} + (t^5 - 3t^4 + 2t^3)^2 - y^2(t),$$

$$y(0) = 0, \quad y'(0) = 0, \quad \alpha = 1.5.$$

The exact solution of this problem is $y(t) = t^5 - 3t^4 + 2t^3$.

t	FEAM3 $N = 10$	PCAM $N = 10$	FEAM3 $N = 1000$	PCAM $N = 1000$
0.0	0.0000×10^0	0.0000×10^0	0.0000×10^0	0.0000×10^0
0.2	4.5689×10^{-2}	6.2246×10^{-7}	1.9701×10^{-6}	1.1876×10^{-8}
0.4	5.8370×10^{-2}	5.2725×10^{-5}	8.8948×10^{-6}	1.9208×10^{-7}
0.6	1.1856×10^{-1}	2.4045×10^{-4}	9.1466×10^{-6}	2.8637×10^{-6}
0.8	1.2003×10^{-1}	4.9761×10^{-4}	1.1237×10^{-6}	5.1521×10^{-6}
1.0	2.4589×10^{-3}	3.8112×10^{-4}	2.1086×10^{-6}	4.6573×10^{-6}

Table 3: Absolute error at each point t when solving Problem 2 using FEAM3 and PCAM for different intervals N and $\alpha = 1.5$

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IKKI NOMA'LUMLI CHIZIQLI GIPERBOLIK TENGLAMALAR SISTEMASI UCHUN ARALASH MASALANING TURGU'NLIGINI LYAPUNOV FUNKSIYASINI QURISH ORQALI TEKSHIRISH

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ANNOTATSIYA. Mazkur tezisda Riman invariantlari yordamida berilgan ikki komponentli chiziqli giperbolik tenglamalar sistemasining aralash masalasi o'rganilgan. Sistema uchun Lyapunov funksiyasi qurilib, uning vaqt bo'yicha hosilasi hisoblandi hamda chegaraviy shartlar yordamida eksponensial turg'unlik sharti keltirib chiqarildi. Chegaraviy parametrlar uchun $|rs| < 1$ sharti bajarilganda sistema yechimining eksponensial so'nishi isbotlandi. Shuningdek, oqimga qarshi ayirmali sxema yordamida sonli yechim qurildi va parametrlarning yechim turg'unligiga ta'siri tahlil qilindi.

Kalit so'zlar: Giperbolik sistema, Riman invariantlari, Lyapunov funksiyasi, eksponensial turg'unlik, aralash masala, chegaraviy shart, ayirmali sxema, sonli yechim.

KIRISH

Giperbolik tenglamalar sistemalari gaz dinamikasi, transport jarayonlari, akustika, mexanika va boshqaruv nazariyasida muhim matematik modellar hisoblanadi. Ayniqsa, bir o'lchovli chiziqli giperbolik sistemalarning chegaraviy boshqaruv masalalari va turg'unligini tadqiq qilish zamonaviy amaliy matematikaning dolzarb yo'nalishlaridan biridir.

Mazkur ishda Riman invariantlari yordamida diagonal ko'rinishga keltirilgan ikki komponentli chiziqli giperbolik sistema qaraladi. Sistema uchun aralash masala qo'yilib, uning

yechimlari Lyapunov funksional usuli yordamida tekshiriladi. Lyapunov funksiyasining vaqt bo'yicha hosilasi hisoblanib, chegaraviy shartlarning sistema energiyasiga ta'siri tahlil qilinadi.

Chegaraviy bog'lanish parametrlariga bog'liq holda eksponensial turg'unlik shartlari keltirib chiqariladi. Xususan, $|rs| < 1$ shart bajarilganda sistema yechimining eksponensial ravishda nolga intilishi ko'rsatildi. Bundan tashqari, sistema uchun oqimga qarshi ayirmali sxema qurilib, sonli tajribalar yordamida nazariy natijalar tasdiqlandi.

Dastavval quyidagi Riman invariantlari yordamida berilgan ikkita giperbolik tenglamalar sistemasini ko'ramiz:

$$\begin{cases} \frac{\partial R_+}{\partial t} + \frac{\partial R_+}{\partial x} = 0 & 0 < x \leq 1 \\ \frac{\partial R_-}{\partial t} - \frac{\partial R_-}{\partial x} = 0 & 0 < t \leq 1 \end{cases} \quad (1)$$

(1) Sistema o'zgaras $a_1 = a_2 = 1$ xarakteristik tezliklarga ega va u quyidagi boshlang'ich:

$$\begin{cases} R_+(x, 0) = \sin(\pi x) \\ R_-(x, 0) = 0 \end{cases} \quad (2)$$

va chegaraviy shartlar bilan aniqlangan:

$$\begin{cases} R_+(0, t) = \sqrt{2} R_-(0, t) \\ R_-(1, t) = \frac{1}{2} R_+(1, t) \end{cases} \quad (3)$$

Sonli yechimni topish uchun quyidagi oqimga qarshi ayirmali to'rdan foydalanamiz:

$$\begin{cases} R_{+,i}^{n+1} = R_{+,i}^n - a_1 \frac{\Delta t}{\Delta x} (R_{+,i}^n - R_{+,i-1}^n) \\ R_{-,i}^{n+1} = R_{-,i}^n - a_2 \frac{\Delta t}{\Delta x} (R_{-,i+1}^n - R_{-,i}^n) \end{cases} \quad (4)$$

Ushbu ishda Lyapunov turg'unligi yondashuviga tayangan holda, (1)–(3) sistema yechimlarining nolga yaqinlashish jarayonini L^2 – fazosida tahlil qilamiz.

Buning uchun eksponensial turg'unlik haqidagi teoremani keltirib olamiz.

Teorema.1. Ixtiyoriy $(u_1(0, t), u_2(0, t)) \in L^2((0, L); \mathbb{R}^2)$ boshlang'ich funksiyalar uchun (1)–(3) aralash masala yagona yechimga ega. Bundan tashqari, shunday musbat aniqlangan C, ν o'zgaraslar mavjudki,

$$\|(u_1(t, \cdot), u_2(t, \cdot))^T\|_{L^2((0, L); \mathbb{R}^2)} \leq C e^{-\nu t}, \quad t \in [0, +\infty)$$

tengsizligi faqat va faqat $|rs| < 1$ bo'lgandagina o'rinli bo'ladi.

Yaqinlashishni tahlil qilish uchun quyidagi Lyapunov funksiyasini kiritamiz:

$$V(t) = \int_0^1 [\mu_1 R_+^2(x, t) e^{-\nu x} + \mu_2 R_-^2(x, t) e^{\nu x}] dx \quad (5)$$

Bu yerda μ_1, μ_2, ν – musbat koeffitsientlar

$$\frac{\partial V(t)}{\partial t} = \int_0^1 \left[2\mu_1 R_+ \frac{\partial R_+}{\partial t} e^{-\nu x} + 2\mu_2 R_- \frac{\partial R_-}{\partial t} e^{\nu x} \right] dx$$

(1) - tenglamalar sistemasidan foydalanib $(R_+)_t$, $(R_-)_t$ ifodalarni mos ravishda $-(R_+)_x$, $(R_-)_x$ bilan almashtirish bajarsak:

$$\begin{aligned} \frac{\partial V(t)}{\partial t} &= \int_0^1 \left[-2\mu_1 R_+ \frac{\partial R_+}{\partial x} e^{-\nu x} + 2\mu_2 R_- \frac{\partial R_-}{\partial x} e^{\nu x} \right] dx = \\ &= \int_0^1 \left[-\mu_1 \frac{\partial (R_+^2)}{\partial x} e^{-\nu x} + \mu_2 \frac{\partial (R_-^2)}{\partial x} e^{\nu x} \right] dx \end{aligned}$$

Bo'laklab integrallashni amalga oshiramiz, bunda:

$$\int u d\vartheta = u\vartheta - \int \vartheta du$$

$$\left[\begin{array}{cc} u = -\mu_1 e^{-vx} & du = v\mu_1 e^{-vx} \\ d\vartheta = \frac{\partial(R_+^2)}{\partial x} & \vartheta = R_+^2 \end{array} \right] \left[\begin{array}{cc} u = \mu_2 e^{vx} & du = v\mu_2 e^{vx} \\ d\vartheta = \frac{\partial(R_-^2)}{\partial x} & \vartheta = R_-^2 \end{array} \right]$$

$$\frac{\partial V(t)}{\partial t} = \left[-\mu_1 R_+^2 e^{-vx} + \mu_2 R_-^2 e^{vx} \right] \Big|_0^1 - v \int_0^1 \mu_1 R_+^2 e^{-vx} + \mu_2 R_-^2 e^{vx} =$$

$$= -\mu_1 R_+^2(1, t) e^{-v} + \mu_2 R_-^2(1, t) e^v + \mu_1 R_+^2(0, t) - \mu_2 R_-^2(0, t) - vV(t)$$

Endi (3) - chegaraviy shartlarni qo'llasak.

$$\frac{\partial V(t)}{\partial t} = -vV(t) - \mu_1 R_+^2(1, t) e^{-v} + \mu_2 s^2 R_+^2(1, t) e^v + \mu_1 r^2 R_-^2(0, t) - \mu_2 R_-^2(0, t) =$$

$$= -vV(t) - [\mu_1 e^{-v} - \mu_2 s^2 e^v] R_+^2(1, t) - [\mu_2 - \mu_1 r^2] R_-^2(0, t)$$

Agar chegaraviy shartlardagi parametrlar $|rs| < 1$ shartni qanoatlantirsa, u holda $v > 0$ ni shunday tanlashimiz mumkinki:

$$\begin{aligned} \mu_1 e^{-v} - \mu_2 s^2 e^v &> 0 \\ \mu_2 - \mu_1 r^2 &> 0 \end{aligned} \Rightarrow \begin{aligned} s^2 e^{2v} &< \frac{\mu_1}{\mu_2} \\ \frac{\mu_1}{\mu_2} &< \frac{1}{r^2} \end{aligned} \Rightarrow e^{2v} r^2 s^2 < 1$$

$$e^{2v} (\sqrt{2})^2 \frac{1}{2^2} = e^{2v} \cdot 2 \cdot \frac{1}{4} = e^{2v} \cdot \frac{1}{2} < 1 \Rightarrow e^{2v} < 2 \Rightarrow 2v < \ln 2$$

$v < \frac{\ln 2}{2}$ demak $v = 0.2$ olsak bo'ladi.

Shundan so'ng μ_1 va μ_2 parametrlarni quyidagicha tanlash mumkin:

$$s^2 e^{2v} < \frac{\mu_1}{\mu_2} < \frac{1}{r^2}$$

$$s^2 e^{2v} = \frac{1}{4} e^{0.4} = \frac{1}{4} 1.4918 \approx 0.373$$

$$\frac{1}{r^2} = \frac{1}{2} = 0.5$$

$$\Rightarrow 0.373 < \frac{\mu_1}{\mu_2} < 0.5 \Rightarrow \begin{aligned} \mu_1 &= 0.4 \\ \mu_2 &= 1 \end{aligned}$$

Endi tanlab olgan $v = 0.2$, $\mu_1 = 0.4$, $\mu_2 = 1$ qiymatlarimizga asoslanib koeffitsiyentlarimizni tekshirib olamiz:

$$\mu_1 e^{-v} - \mu_2 s^2 e^v = 0.4 \cdot e^{-0.2} - \frac{1}{4} e^{0.2} = 0.0222 > 0$$

$$\mu_2 - \mu_1 r^2 = 1 - 0.4 \cdot 2 = 0.2 > 0$$

Demak

$$\frac{\partial V(t)}{\partial t} \leq -vV(t)$$

sistema eksponensial turg'un ekanligi kelib chiqadi.

XULOSA

Mazkur ishda ikki komponentli chiziqli giperbolik tenglamalar sistemasining aralash masalasi Riman invariantlari yordamida tadqiq qilindi. Sistema uchun maxsus Lyapunov funksional qurilib, uning vaqt bo'yicha hosilasi hisoblandi. Chegaraviy shartlarni qo'llash natijasida sistema eksponensial turg'un bo'lishi uchun $|rs| < 1$ shart yetarli ekanligi ko'rsatildi.

Shuningdek, oqimga qarshi ayirmali sxema yordamida sistema sonli yechildi va chegaraviy parametrlarning yechim xatti-harakatiga ta'siri tahlil qilindi. Sonli natijalar nazariy tahlil bilan mos kelishi kuzatildi. Parametrlar turg'unlik shartini qanoatlantirganda yechim vaqt o'tishi bilan turg'unligi, aks holda esa turg'un emasligi aniqlandi.

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ОБ ОДНОЙ СИСТЕМЕ ТИПА ВИНЕРА-ХОПФА ДЛЯ НАХОЖДЕНИЙ ОПТИМАЛЬНЫХ КОЭФФИЦИЕНТОВ ИНТЕРПОЛЯЦИОННЫХ ФОРМУЛ

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Настоящая работа посвящена получению систему алгебраических уравнений для нахождения оптимальных коэффициентов интерполяционных формул в гильбертовом пространстве $W_2^{(m,0)}(0,1)$.

Предположим, что нам дана таблица значений $\varphi(x_\beta), \beta=0,1,\dots,N$ функции φ в точках $x_\beta \in [0,1]$. Требуется аппроксимировать функцию φ другой, более простой функцией P_φ , т. е.

$$\varphi(z) \cong P_\varphi(z) = \sum_{\beta=0}^N C_\beta(z) \varphi(x_\beta), \quad (1)$$

где $P_\varphi(z) = \sum_{\beta=0}^N C_\beta(z) \varphi(x_\beta)$ -- интерполяционная формула и

$$\ell(x, z) = \delta(x - z) - \sum_{\beta=0}^N C_\beta(z) \delta(x - x_\beta) \quad (2)$$

- функционал погрешности этой интерполяционной формулы, $C_\beta(z)$ - коэффициенты, а x_β - узлы интерполяционной формулы $P_\varphi(z)$, $x_\beta \in [0,1]$, $\delta(x)$ - дельта-функция Дирака, функция $\varphi(x)$ принадлежит гильбертову пространству $W_2^{(m,0)}(0,1)$. Норма функций в этом пространстве определяется следующим образом

$$\|\varphi(x)\|_{W_2^{(m,0)}} = \left[\int_0^1 \left(\varphi^{(m)}(x) - \varphi(x) \right)^2 dx \right]^{1/2}. \quad (3)$$

Здесь m – нечётное натуральное число. Погрешностью интерполяционной формулы (1) называется разность

$$(\ell, \varphi) = \varphi(z) - P_\varphi(z) = \varphi(z) - \sum_{\beta=0}^N C_\beta(z) \varphi(x_\beta). \quad (4)$$

Задача построения оптимальных интерполяционных формул в пространстве $W_2^{(m,0)}(0,1)$ это вычисление следующей величины:

$$\left\| \ell \right\|_{W_2^{(m,0)}^*} = \inf_{C_\beta(z)} \left\| \ell \right\|_{W_2^{(m,0)}^*}. \quad (5)$$

Напомним, что погрешность формулы (1) является линейным функционалом в $W_2^{(m,0)*}(0,1)$, где $W_2^{(m,0)*}(0,1)$, сопряженное пространство к пространству $W_2^{(m,0)}(0,1)$.

Эта задача состоит из двух частей: сначала мы должны вычислить норму $\|\ell\|_{W_2^{(m,0)*}}$ функционала погрешности в пространстве $W_2^{(m,0)*}(0,1)$, а потом минимизировать его по коэффициентам $C_\beta(z)$.

В работе [1] вычислена норма функционала погрешности. Для нее получено следующее выражение.

$$\|\ell\|_{W_2^{(m,0)*}}^2 = \sum_{\beta=0}^N \sum_{\gamma=0}^N C_\beta(z) C_\gamma(z) G_m(x_\beta - x_\gamma) - 2 \sum_{\beta=0}^N C_\beta(z) G_m(z - x_\beta). \quad (6)$$

А для оптимальных коэффициентов получена система линейных алгебраических уравнений типа Винера-Хопфа:

$$\begin{aligned} \sum_{\gamma=0}^N C_\gamma(z) G_m(x_\beta - x_\gamma) + d_0(z) e^{x_\beta} + d_{1,k}(z) e^{x_\beta \cos \frac{2\pi k}{m}} \cos\left(x_\beta \sin \frac{2\pi k}{m}\right) + \\ + d_{2,k}(z) e^{x_\beta \cos \frac{2\pi k}{m}} \sin\left(x_\beta \sin \frac{2\pi k}{m}\right) = G_m(z - x_\beta), \beta = \overline{0, N}, \end{aligned} \quad (7)$$

$$\sum_{\gamma=0}^N C_\gamma(z) e^{x_\gamma} = e^z, \quad (8)$$

$$\sum_{\gamma=0}^N C_\gamma(z) e^{x_\gamma \cos \frac{2\pi k}{m}} \cos\left(x_\gamma \sin \frac{2\pi k}{m}\right) = e^{z \cos \frac{2\pi k}{m}} \cos\left(z \sin \frac{2\pi k}{m}\right), \quad (9)$$

$$\sum_{\gamma=0}^N C_\gamma(z) e^{x_\gamma \cos \frac{2\pi k}{m}} \sin\left(x_\gamma \sin \frac{2\pi k}{m}\right) = e^{z \cos \frac{2\pi k}{m}} \sin\left(z \sin \frac{2\pi k}{m}\right), \quad (10)$$

где

$$G_m(x) = \frac{\text{sign}(x)}{2m} \left[\text{sh}(x) + \sum_{k=1}^{m-1} e^{x \cos\left(\frac{\pi k}{m}\right)} \cos\left(x \sin\left(\frac{\pi k}{m}\right) + \frac{\pi k}{m}\right) \right].$$

Система (7)-(10) имеет единственное решение. Доказательство единственности решения системы (7)-(10) аналогично доказательству единственности решения системы для оптимальных коэффициентов в пространстве $L_2^{(m)}(0,1)$, полученных в работах Соболева [2,3].

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ОБ ОДНОЙ ДИСКРЕТНОЙ СИСТЕМЕ ТИПА ВИНЕРА-ХОПФА ДЛЯ НАХОЖДЕНИЙ ОПТИМАЛЬНЫХ КОЭФФИЦИЕНТОВ ВЕСОВЫХ КВАДРАТУРНЫХ ФОРМУЛ

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Настоящая работа посвящена получению системы алгебраических уравнений для нахождения оптимальных коэффициентов весовых квадратурных формул в гильбертовом пространстве $W_2^{(m,0)}(0,1)$.

Рассмотрим следующую весовую квадратурную формулу:

$$\int_0^1 e^{2\pi i \omega x} \varphi(x) dx \cong \sum_{\beta=0}^N C_\beta \varphi(x_\beta), \quad (1)$$

где C_β — коэффициенты, x_β — узловые точки, $i^2 = -1$ и $\omega \in \mathbb{Z} \setminus \{0\}$. Функции $\varphi(x)$ принадлежат гильбертову пространству $W_2^{(m,0)}(0,1)$, которое определяется как

$$W_2^{(m,0)}(0,1) = \{\varphi(x) : [0,1] \rightarrow \mathbb{R}, \varphi^{(m-1)}(x) \text{ — абсолютно непрерывна, } \varphi^{(m)}(x) \in L_2(0,1)\}$$

— гильбертово пространство комплекснозначных функций, m — нечётное число, и в этом пространстве скалярное произведение двух функций φ и ψ определяется равенством

$$(\varphi, \psi) = \int_0^1 (\varphi^{(m)}(x) + \varphi(x)) (\overline{\psi^{(m)}(x)} + \overline{\psi(x)}) dx, \quad (2)$$

где $\overline{\psi}$ — сопряжённая функция функции ψ , а норма функции φ определяется, соответственно, по формуле

$$\|\varphi\| = (\varphi, \varphi)^{1/2}$$

и

$$(\varphi, \varphi)^{1/2} = \int_0^1 (\varphi^{(m)}(x) + \varphi(x)) (\overline{\varphi^{(m)}(x)} + \overline{\varphi(x)}) dx < \infty.$$

Напомним, что коэффициенты C_β зависят от ω, N и m , т.е. $C_\beta = C_\beta(\omega, N, m)$. Разность между интегралом и квадратурной суммой в рассматриваемой формуле (1):

$$(\ell, \varphi) = \int_0^1 e^{2\pi i \omega x} \varphi(x) dx - \sum_{\beta=0}^N C_\beta \varphi(x_\beta) = \int_{-\infty}^{\infty} (\varepsilon_{[0,1]}(x) e^{2\pi i \omega x} - \sum_{\beta=0}^N C_\beta \delta(x - x_\beta)) \varphi(x) dx \quad (3)$$

называется погрешностью квадратурной формулы. Для полученного выражения (3) получается следующий функционал погрешности, соответствующий сопряжённому пространству $W_2^{(m,0)*}$:

$$\ell(x) = \varepsilon_{[0,1]}(x) e^{2\pi i \omega x} - \sum_{\beta=0}^N C_\beta \delta(x - x_\beta), \quad (4)$$

где $\varepsilon_{[0,1]}(x)$ — характеристическая функция интервала $[0, 1]$, а $\delta(x)$ — дельта-функция Дирака.

Задача построения оптимальных весовых квадратурных формул в пространстве $W_2^{(m,0)}(0,1)$ это вычисление следующей величины:

$$\|\ell\|_{W_2^{(m,0)*}} = \inf_{C_\beta} \|\ell\|_{W_2^{(m,0)*}(0,1)}. \quad (5)$$

Напомним, что погрешность формулы (1) является линейным функционалом в $W_2^{(m,0)*}(0,1)$, где $W_2^{(m,0)*}(0,1)$, сопряжённое пространство к пространству $W_2^{(m,0)}(0,1)$.

Эта задача состоит из двух частей: сначала мы должны вычислить норму $\|\ell\|_{W_2^{(m,0)*}}$ функционала погрешности в пространстве $W_2^{(m,0)*}(0,1)$, а потом минимизировать его по коэффициентам $C_\beta(z)$.

В работе [1] вычислена норма функционала погрешности. Для нее получено следующее выражение.

$$\| \ell \|^2 = (-1)^m \left[\sum_{\beta=0}^N \sum_{\gamma=0}^N C_{\beta} \bar{C}_{\gamma} G_m(h\beta - h\gamma) - \sum_{\beta=0}^N \int_0^1 (\bar{C}_{\beta} e^{2\pi i \omega x} + C_{\beta} e^{-2\pi i \omega x}) G_m(x - h\beta) dx + \right. \\ \left. + \int_0^1 \int_0^1 e^{2\pi i \omega x} e^{-2\pi i \omega y} G_m(x - y) dx dy \right]. \quad (6)$$

А для оптимальных коэффициентов получена система линейных алгебраических уравнений типа Винера-Хопфа:

$$\sum_{\gamma=0}^N C_{\gamma} G_m(x_{\beta} - x_{\gamma}) + d_0 e^{-x_{\beta}} + d_{1,k} e^{-x_{\beta} \cos \frac{2\pi k}{m}} \cos \left(x_{\beta} \sin \frac{2\pi k}{m} \right) + \\ + d_{2,k} e^{-x_{\beta} \cos \frac{2\pi k}{m}} \sin \left(x_{\beta} \sin \frac{2\pi k}{m} \right) = f_m(x_{\beta}), \beta = \overline{0, N}, \quad (7)$$

$$\sum_{\gamma=0}^N C_{\gamma} e^{-x_{\gamma}} = \int_0^1 e^{2\pi i \omega x} e^{-x} dx, \quad (8)$$

$$\sum_{\gamma=0}^N C_{\gamma} e^{-x_{\gamma} \cos \frac{2\pi k}{m}} \cos \left(x_{\gamma} \sin \frac{2\pi k}{m} \right) = \int_0^1 e^{2\pi i \omega x} e^{-x \cos \frac{2\pi k}{m}} \cos \left(x \sin \frac{2\pi k}{m} \right) dx, \quad (9)$$

$$\sum_{\gamma=0}^N C_{\gamma} e^{-x_{\gamma} \cos \frac{2\pi k}{m}} \sin \left(x_{\gamma} \sin \frac{2\pi k}{m} \right) = \int_0^1 e^{2\pi i \omega x} e^{-x \cos \frac{2\pi k}{m}} \sin \left(x \sin \frac{2\pi k}{m} \right) dx, \quad (10)$$

где

$$G_m(x) = \frac{\text{sign}(x)}{2m} \left[\text{sh}(x) + \sum_{k=1}^{m-1} e^{x \cos \left(\frac{\pi k}{m} \right)} \cos \left(x \sin \left(\frac{\pi k}{m} \right) + \frac{\pi k}{m} \right) \right] \text{ и } f_m(x_{\beta}) = \int_0^1 e^{2\pi i \omega x} G_m(x - x_{\beta}) dx.$$

Система (7)-(10) имеет единственное решение. Доказательство единственности решения системы (7)-(10) аналогично доказательству единственности решения системы для оптимальных коэффициентов в пространстве $L_2^{(m)}(0,1)$, полученных в работах Соболева [2,3].

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NUMERICAL SOLUTION OF NONLINEAR SYSTEMS OF DIFFERENTIAL EQUATIONS USING COMBINED RUNGE-KUTTA AND PIECEWISE CONSTANT ARGUMENT METHODS

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We consider two system of equations

$$\begin{cases} y_1' = f_1(t, y_1, y_2), \\ y_2' = f_2(t, y_1, y_2), \end{cases} \quad t \in [a, b] \quad (1)$$

with initial conditions $y_1(a) = y_{10}$, $y_2(a) = y_{20}$, where f_i , $i = 1, 2$ are real valued differentiable functions are continuous functions on $[a, b] \times \mathbb{R}$, and y_{10} and y_{20} are real constants.

We introduce a system of differential equations with piecewise constant arguments corresponding to the nonlinear differential equation (1). Let n be a positive integer, and define $t_k = kh + a$, where $h = \frac{b-a}{n}$ and $k = 0, 1, 2, \dots, n$. For $t \in [t_k, t_{k+1})$ with $k = 0, 1, 2, \dots, n$, consider the following differential equation with piecewise constant arguments.

The numerical approximation to the solution of (1) using the classical seventh-order Runge-Kutta method is given by:

$$\frac{y_{ik+1} - y_{ik}}{h} = K_i(t_k), \quad y_i(t_0) = y_{i0}, \quad t \in [t_k, t_{k+1}), \quad k = 0, 1, 2, \dots, n-1. \quad (2)$$

where the increment function $K_i(t_k)$ is computed as a weighted sum of the intermediate stage derivatives [2]:

$$\begin{aligned} K_1(t_k) &= y_{1k} + \frac{31}{720}k_1 + \frac{16}{75}k_6 + \frac{16807}{79200}k_7 + \frac{16807}{79200}k_8 + \frac{243}{1760}k_9 + \frac{243}{1760}k_{12} + \frac{31}{720}k_{13}, \\ K_2(t_k) &= y_{2k} + \frac{31}{720}l_1 + \frac{16}{75}l_6 + \frac{16807}{79200}l_7 + \frac{16807}{79200}l_8 + \frac{243}{1760}l_9 + \frac{243}{1760}l_{12} + \frac{31}{720}l_{13}, \end{aligned}$$

For any given positive integer n , we define an auxiliary differential equation with a piecewise constant argument that corresponds to the nonlinear differential equation in (1) as follows:

$$y'_i(t) = F_i(t), \quad y_i(t_0) = y_{i0}, \quad i = 1, 2, \quad t \in (a, b). \quad (3)$$

where

$$F_i(t) = K_i(t_k) \quad \text{for } t \in [t_k, t_{k+1}), \quad k = 0, 1, 2, \dots, n-1,$$

the values y_k are defined by

$$y_{k+1} = y(t_{k+1}) = \lim_{t \rightarrow t_{k+1}-0} \int_{t_k}^t F_i(s) ds = K_i(t_k) \frac{b-a}{n}.$$

Due to the construction of $K_i(t_k)$, it satisfies the following asymptotic consistency condition:

$$K_i(t_k) - f_i(t_k, y_{1k}, y_{2k}) \rightarrow 0 \quad \text{as } n \rightarrow \infty. \quad (4)$$

Definition 1. A vector function $(y_1(t), y_2(t))$ is called a solution of the initial value problem (3) if the following conditions are satisfied:

1. $y_1(t), y_2(t)$ are continuous on the interval $[a, b]$;
2. $y_{1'}(t), y_{2'}(t)$ exist and continuous on $[a, b]$ with possible exception at points $t = t_{k+1}$, where $k = 0, 1, \dots, n-1$, at which the one-sided derivatives exist;
3. The function $y_1(t), y_2(t)$ satisfies the differential equation in (3) for all $t \in (a, b)$, possible excluding the points $t = t_{k+1}$, where $k = 0, 1, \dots, n-1$.

Theorem 1. For any positive integer number n , the initial value problem (3) has a unique solution $(y_1(t), y_2(t)) := (y_{1n}(t), y_{2n}(t))$, as defined in

$$y_i(t) = K_i(t_{k-1})(t - t_{k-1}) + y_i(t_{k-1}), \quad i = 1, 2, \quad k = 2, 3, \dots, n.$$

The following theorem claims that the vector (y_{1n}, y_{2n}) can be approximated solution for the initial value problem (1) for large n .

Theorem 2. For any given $\varepsilon > 0$, there exists a positive integer $n_0 = n(\varepsilon)$ such that for all integers $n > n_0$, the following inequality

$$\sup_{t \in [a, b]} |y_{in}'(t) - K_i(t)| < \varepsilon, \quad i = 1, 2$$

holds, where (y_{1n}, y_{2n}) denotes the solution of the initial value problem (3).

Test Problem 1. Taking the linear stiff system [1]

$$\begin{aligned} y_{1'}(t) &= -y_1(t) + 95y_2(t), \\ y_{2'}(t) &= -y_1(t) - 97y_2(t), \end{aligned}$$

with given initial conditions $y_1(0) = 1, \quad y_2(0) = 1$. The exact solution is

$$y_1(t) = 95e^{-2t} - 48e^{-96t}/47, \quad y_2(t) = 48e^{-96t} - e^{-2t}/47.$$

Table 1: Numerical results for Test Problem 1 obtained using the higher-order Haar wavelet collocation method (H-HWCM) and the present method, where RC denotes a rate of convergence.

N	H-HWCM method				Present method			
	MaxErr(y_1)	MaxErr(y_2)	RC	CPU	MaxErr(y_1)	MaxErr(y_2)	RC	CPU
32	5.6470E-02	5.6470E-02	—	0.11	7.7242E-03	7.7242E-03	—	2.52

64	$6.6887E-03$	$6.6887E-03$	3.08	0.29	$1.4138E-05$	$1.4138E-05$	9.09	2.73
128	$5.3416E-04$	$5.3416E-04$	3.65	0.85	$3.2308E-08$	$3.2308E-08$	8.77	2.93
256	$4.2096E-05$	$4.2096E-05$	3.67	3.48	$1.0206E-10$	$1.0206E-10$	8.31	3.37
512	$2.9462E-06$	$2.9462E-06$	3.84	13.27	$3.5877E-13$	$3.5877E-13$	8.15	4.23

Test Problem 2. Consider the nonlinear system of differential equations with variable coefficients [1]

$$y_{1'}(t) = \cos(t) + y_1^2(t) + y_2(t) - (1 + t^2 + \sin^2(t)),$$

$$y_{2'}(t) = 2t - (1 + t^2)\sin(t) + y_1(t)y_2(t)$$

with given initial conditions $y_1(0) = 0$ and $y_2(0) = 1$.

The exact solution is $y_1(t) = \sin(t)$, $y_2(t) = 1 + t^2$.

Table 2: Comparison of H-HWCM with Present method for Test Problem 2.

N	HWCM		H-HWCM		Present method	
	$MaxErr(y_1)$	$MaxErr(y_2)$	$MaxErr(y_1)$	$MaxErr(y_2)$	$MaxErr(y_1)$	$MaxErr(y_2)$
16	1.7431E-03	2.4924E-03	1.6904E-04	1.0579E-05	2.8361E-11	4.3974E-11
32	4.5390E-04	6.4206E-04	8.0472E-05	2.5718E-06	7.3594E-14	9.4638E-14
64	1.1598E-04	1.6315E-04	3.9270E-05	6.3332E-07	3.8342E-16	5.2551E-16
128	2.9324E-05	4.1138E-05	1.9399E-05	1.5708E-07	2.4825E-18	3.6010E-18

Test Problem 3. Source [3]

$$y_{1'}(t) = 42y_2(t) - 43y_1(t),$$

$$y_{2'}(t) = -8y_2(t) + 7y_1(t)$$

$y_1(0) = 8$, $y_2(0) = 1$, $0 \leq t \leq 1$. Exact solution: $y_1(t) = 2e^{-t} + 6e^{-50t}$, $y_2(t) = 2e^{-t} - e^{-50t}$.

$MaxErr = |y_{ni}(t) - y_i(t)|$, where y_i is the exact solution for the problem and y_{ni} is the computed solution.

Table 3: Numerical results for Test Problem 3.

h	Method	MAXE
10^{-2}	HBBDF	2.3743E-01
	BBDF(5)	1.9713E-01
	ode15s	5.0258E-02
	Present method	6.5190E-09
10^{-4}	HBBDF	9.4970E-05
	BBDF(5)	3.9449E-04
	ode15s	3.9699E-04
	Present method	4.8760E-25

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ВЫЧИСЛИМАЯ НУМЕРАЦИЯ НАД МНОЖЕСТВОМ КОНСТРУКТИВНЫХ ДЕЙСТВИТЕЛЬНЫХ ЧИСЕЛ

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Аннотация. В данной работе изучается понятие вычислимой нумерации над множеством конструктивных действительных чисел. Приводится определение конструктивных действительных чисел и анализируются их нумерации и свойства.

В конструктивном анализе действительные числа определяются как фундаментальные последовательности рациональных чисел с алгоритмическим регулятором сходимости [1,3]. Такие числа называются конструктивными действительными числами. Важным инструментом их исследования является теория нумераций [2]. В данной работе рассматриваются вычислимые нумерации над множеством конструктивных действительных чисел.

Последовательностью натуральных (рациональных) чисел будем называть алгоритм (в алфавите $\mathcal{L}$) типа $(\mathbb{N} \rightarrow \mathbb{N})$ (соответственно типа $(\mathbb{N} \rightarrow \mathbb{Q})$). Вместо термина «последовательность натуральных (рациональных) чисел» мы будем часто использовать сокращение ПНЧ (ПРЧ).

Определение 1. ПНЧ β называется регулятором сходимости в себе (или регулятором фундаментальности) ПРЧ α , если

$$\forall n \forall m, l [m, l \geq \beta(n) \Rightarrow |\alpha(m) - \alpha(l)| < 2^{-n}].$$

Определение 2. Слово Q в алфавите $\mathcal{L}$ назовем конструктивным действительным числом (или, короче, КДЧ), если Q является рациональным числом или $Q = (\alpha, \beta)$, где α — ПРЧ, β — ПНЧ, являющаяся регулятором сходимости в себе ПРЧ α .

Определение 3. Пусть $\mathbb{R}_c$ — множество КДЧ и $A \subseteq \mathbb{R}_c$. Любая сюръекция $v : \mathbb{N} \rightarrow A$ называется нумерацией A .

Определение 4. Нумерация v семейства A называется вычислимой, если существует вычислимая функция f т.ч. $v(x) = \varphi_{f(x)}$ для всех x .

Определение 5. Нумерация $v : \mathbb{N} \rightarrow A$ множества $A \subseteq \mathbb{R}_c$ называется псевдоинъективной, если:

$$\forall m \forall n (m \neq n \Rightarrow \neg \neg (v(m) \neq v(n)))$$

или, эквивалентно (в логике с слабым отрицанием):

$$\forall m \forall n (\neg \neg (v(m) = v(n)) \Rightarrow m = n).$$

Равенство на A разрешимо $\Leftrightarrow$ существует алгоритм, который по двум номерам $m, n \in \mathbb{N}$ определяет, равны ли $v(m)$ и $v(n)$ как элементы $\mathbb{R}_c$

Возникает естественный вопрос: если некоторое бесконечное подмножество $A \subseteq \mathbb{R}_c$ имеет вычислимую нумерацию, то можно ли построить для него вычислимую нумерацию, обладающую дополнительными свойствами, такими как инъективность или псевдоинъективность? Получена следующая теорема.

Теорема. Любое бесконечное множество $A \subseteq \mathbb{R}_c$ с вычислимой нумерацией имеет псевдоинъективную вычислимую нумерацию, но инъективная существует тогда и только тогда, когда равенство на A разрешимо.

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**КЛАССИК ФАЗО. (НОНОРМАЛЛАНГАН ФАЗО, И.М. ГЕЛЬФАНД
(1961) МУАММОСИНИНГ БАЪЗИ ЕЧИМИ)
Мадрахимов Рузимбай Машарипович**

Аннотация. Ушбу мақолада нормалланган фазо тушунчасини янгилаш зарурли асосланган ва янги “**классик фазо**” тушунчаси киритилади. У Израил Моисович Гельфанд тамонидан қўйилган муаммонинг баъзи ечими бўлади.

Фаннинг ҳамма соҳасида ҳам абадий ўзгармас ҳақиқатлар бўлмайди. Билишнинг турли воситалари узлуксиз ва жадал ривожлана бориши бизни аввал равшан бўлган ҳодисаларга бошқача қарашга ва унинг янги, аввалгидан мутлоқ фарқли моҳиятини кўришга олиб келади. Математика фани ҳам шулар жумласидан. Масофа, норма тушунчаси йигирманчи асрнинг бошларида киритилган. У Банах ва унинг шогирдлари тамонидан ривожлантирилди. 1961 йилда ёзда математикларнинг IV бутуниттифок съезди бўлиб ўтди. Съездда жуда катта муаммолар ўртага ташланди. Муаммо қўйганлардан бири Израил Моисович Гельфанддир. У фазо таърифида аксиоматик етишмавчилик бор эканлигини тушқин кайфиятда баён қилди. Бу фикрлар таниқли математикларнинг назаридан четда қолмади. Бу ҳақда муаллифлари Н.Я.Великин ва бошқалардан иборат бўлган, С.Г.Крейн таҳрири остида 1964 йилда чиққан, “Функциональный анализ” (қаранг[3]) китобида айтиб ўтилган. Бу китоб редакторининг сўз бошисида эътибор Израил Моисович Гельфанднинг муаммосига қаратилган. Ҳақиқатан, Израил Моисович Гельфанднинг фикрларини асослашга киришамиз. Қуйидаги

$f(W) = W^{-1}$, $W \in C[n \times n]$ матрицавий функцияни қараймиз. Агар $n = 1$ га тенг бўлса, $\|W\| > 0$ да берилган функция аниқланган. **Чунки бу ҳолда** юқоридаги функциянинг битта $W = 0$ нуқтада махсус нуқтаси бор. Агар $n > 1$ бўлса вазият умуман бошқача бўлади. $\|W\| > 0$ да берилган функция аниқланмаган бўлади. **Чунки бунда махсуслик $\det W = 0$** , бу эса гиперсиртдир. $C[n \times n]$ да ихтиёрий нормани олганимизда ҳам юқоридаги вазият рўй беради. Демак нормал фазо аксиомалари $C[n \times n]$ да берилган юқоридаги матрица аргументли функциянинг хоссаларини ўрганиш учун етарли бўлмайди. Биз шундай норма топишимиз керакки, унда $\|W\| > 0 \Leftrightarrow \det W \neq 0$ бўлиши керак.

1-теорема. $W \in C[n \times n]$ бўлсин. У ҳолда $\det W \neq 0 \Leftrightarrow WW^* > 0$.

Ушбу мақолада ана шу масаланинг ечими бўлган нормалланган фазонинг мутлақо янги тарифи берилади.

1-таъриф. Қуйидаги аксиомаларни қанотлантирадиган фазога **классик фазо** дейилади.

I. (Норма аксиомаси) $\|*\|: C[n \times n] \rightarrow R^+$ функция ихтиёрий $A, B \in C[n \times n]$ лар учун қуйидаги аксиомаларни қанотлантирса:

- 1) $\|A\| \geq 0$, $\|A\| = 0 \Leftrightarrow A = \theta$
- 2) $\|\mu A\| = |\mu| \|A\| \quad \forall \mu \in C$
- 3) $\|A + B\| \leq \|A\| + \|B\|$
- 4) $\|AB\| \leq \|A\| \|B\|$

II. (Псевдонорма аксиомаси) $M^+ = \{AA^*: A \in C[n \times n] \text{ элементлари комплекс сонлардан иборат ҳамма матрицалар}\}$. $\|*\|: C[n \times n] \rightarrow M^+$ акслантириш қуйидаги аксиомаларни қанотлантирса: Место для уравнения.

- а) $\|A\| \geq \theta$, $\|A\| = \theta$ шу ҳолда ва фақат шу ҳолдаки, $A = \theta$.
- б) $\|\beta A\| = |\beta| \|A\|$ ихтиёрий β комплекс сон учун
- в) $\sqrt{2} (\|A\| + \|B\|) - \|A + B\| \geq \theta$ псевдо учбурчак тенгсизлиги

$C[n \times n]$ элементлари комплекс сонлардан иборат n тартибли ҳамма матрицалар, бўлсин. У ҳолда $A \in C[n \times n]$ A матрицанинг ўнг (Right) абсолют қиймати (чап (Left) абсолют қиймати) деб қуйидаги микдорга айтамыз $|A|_R = \sqrt{A^*A}$ ($|A|_L = \sqrt{AA^*}$).

1-мисол $A \in C[n \times n]$ даги ҳамма матрицалар учун матрицаларнинг спектрал нормаси ва псевдонормани $\|A\| = |A|_R = \sqrt{A^*A}$ ёки $\|A\| = |A|_L = \sqrt{AA^*}$ тенглик орқали аниқлаймиз.

(қаранг[6], [7], [8]) Бу юқоридаги таърифга кўра **классик фазо** бўлади.

Бу ердаги псевдонорма учун одатдаги учбурчак тенгсизлиги бажарилмайди.

2-мисол (Э.Нельсон, қ.[5], 241бет, 16 масала)

$$B = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, C = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \text{ бўлса, у ҳолда}$$

$$|||B + I||| + |||C - I||| - |||(B + I) + (C - I)||| \not\geq 0$$

2-теорема. Агар $A \in C[n \times n]$ ва $\det A \neq 0$ бўлса, у ҳолда $|||A|||^2 |||A^{-1}|||^2 = I$ яъни, матрицавий псевдонорма идеал шаклланган.

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THE DYNAMICS OF A 2-VOLTERRA QUADRATIC OPERATOR

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Let $E = \{1, \dots, m\}$ be a finite set and the set of all probability distributions on E

$$S^{m-1} = \left\{ x = (x_1, x_2, \dots, x_m) \in R^m : x_i \geq 0, \text{ for any } i \text{ and } \sum_{i=1}^m x_i = 1 \right\}$$

be the $(m-1)$ -dimensional simplex. A map V of S^{m-1} into itself is called a *quadratic stochastic operator* (QSO) if

$$(Vx)_k = \sum_{i,j=1}^m p_{ij,k} x_i x_j \quad (1)$$

for any $x \in S^{m-1}$ and for all $k = 1, \dots, m$ where

$$p_{ij,k} \geq 0, p_{ij,k} = p_{ji,k}, \sum_{k=1}^m p_{ij,k} = 1. \quad (2)$$

In [1] developed the theory of Volterra QSOs. A Volterra QSO is defined by (1), (2) and with the additional assumption

$$p_{ij,k} = 0, \text{ for any } k \notin \{i, j\}, i, j, k = 1, \dots, m.$$

The trajectory $\{x^{(n)}\}_{n \geq 0}$ of a point $x \in S^{m-1}$ for an operator V is defined by $x^{(n+1)} = V(x^{(n)})$ for all $n = 0, 1, 2, \dots$, where $x^{(0)} = x$.

Denote by $\omega_V(x^{(0)})$ the set of limit points of the trajectory $\{x^{(n)}\}_{n \geq 0}$.

Definition 1. A point $x \in S^{m-1}$ is called a *periodic point* of V if there exists an n so that $V^n(x) = x$. The smallest positive integer n satisfying the above is called the *prime period* or *least*

period of the point x . A period-one point is called a *fixed point* of V . Denote the set of all fixed points by $Fix(V)$ and the set of all periodic points of (not necessarily prime) period n by $Per_n(V)$.

Let $D(V(x^*)) = (\partial V_i / \partial x_j)(x^*)$ be a Jacobian of V at the point x^* .

Definition 2. A *fixed point* x^* is called hyperbolic if its Jacobian $D(V(x^*))$ has no eigenvalues equal 1 in absolute value. A hyperbolic fixed point x^* is called:

- *attracting*, if all the eigenvalues of the Jacobian $D(V(x^*))$ are less than 1 in absolute value;
- *repelling*, if all the eigenvalues of the Jacobian $D(V(x^*))$ are greater than 1 in absolute value;
- a *saddle*, otherwise.

We consider a quadratic operator $V: \mathbb{R}^3 \rightarrow \mathbb{R}^3$ which has the form

$$V: \begin{cases} x' = x(1 - b + dy - ez) \\ y' = y(1 - a - dx + cz) \\ z' = z(1 - cy + ex) + ay + bx \end{cases} \quad (3)$$

Where $a, b, c, d, e \in \mathbb{R}$.

It worth mentioning that if $a = b = c = d = e = 0$ then V is the identity map;

Proposition. The operator (3) maps S itself if and only if

$$0 \leq a, b \leq 1, \quad b - 1 \leq d \leq -a, \quad -b - \sqrt{b} - 1 \leq e \leq -b, \quad a - 1 \leq c \leq a + \sqrt{a} + 1. \quad (4)$$

Denote by $\Gamma_{ij} = \{x \in S^2 : x_k = 0; k \notin \{i, j\}\}$, $i \neq j, i, j \in \{1, 2, 3\}$ the faces of S^2 and by $e_1 = (1, 0, 0)$, $e_2 = (0, 1, 0)$, $e_3 = (0, 0, 1)$ the vertices of the S^2 .

Theorem 1. For the operator (3) with parameters (4) the following statements hold:

- (i) If $a = c = 0$ and $bde \neq 0$ then $Fix(V) = \Gamma_{23} \cup \left\{ \left(1 + \frac{b}{e}, 0, -\frac{b}{e} \right) \right\}$ and

$$\omega_V(x^{(0)}) = \{x^*\}, x^* \in \Gamma_{23} \text{ for any } x^{(0)} \in S^2 \setminus \left(\Gamma_{23} \cup \left\{ \left(1 + \frac{b}{e}, 0, -\frac{b}{e} \right) \right\} \right);$$

- (ii) If $b = d = 0$ and $ace \neq 0$ then $Fix(V) = \left\{ e_1, e_3, \left(0, 1 - \frac{a}{c}, \frac{a}{c} \right) \right\}$ and

$$\omega_V(x^{(0)}) = \begin{cases} \{e_1\}, & x^{(0)} \in S^2 \setminus \left(\Gamma_{23} \cup \left\{ \left(0, 1 - \frac{a}{c}, \frac{a}{c} \right) \right\} \right) \\ \left\{ \left(0, 1 - \frac{a}{c}, \frac{a}{c} \right) \right\}, & x^{(0)} \in \Gamma_{23} \end{cases}.$$

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CENTRAL LIMIT THEOREM FOR FIRST-ORDER AUTOREGRESSIVE PROCESSES WITH VALUES IN $L_p[0,1]$

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In this paper, AR(1)-processes with values in the $L_p[0,1]$ are analyzed. Assuming weak dependence of the innovations, a central limit theorem for AR(1)-processes is proved. Papers [1] and [2] focused on AR(1)-processes assuming independence or weak orthogonality. In [3], the authors later analyzed the asymptotic behavior of the empirical mean and covariance operator when the noise sequence satisfies a weak dependence condition. Since observations in functional data analysis are functions instead of real numbers, AR(1)-models in $L_p[0,1]$ naturally emerge in this framework.

We study an AR(1)-process $\{X_n, n \in \mathbb{Z}\}$ defined by the recursive relation

$$X_n - \mu = T(X_{n-1} - \mu) + \varepsilon_n, \quad n \in \mathbb{Z}$$

where $T: L_p[0,1] \rightarrow L_p[0,1]$ is a bounded linear operator, $\mu \in L_p[0,1]$ denotes a fixed mean element and $\{\varepsilon_n, n \in \mathbb{Z}\}$ is the innovation sequence. The notation $\|T\|$ denotes the norm of the operator $T: L_p[0,1] \rightarrow L_p[0,1]$, and $I: L_p[0,1] \rightarrow L_p[0,1]$ denotes the identity operator. Consider an $L_p[0,1]$ -valued stochastic process $\{X_n(t), n \in \mathbb{Z}\}$, and let $\mathcal{F}_r^s$ be the σ -algebra generated by $(X_r(t), \dots, X_s(t))$. We define the classical mixing coefficients by

$$\alpha(n) = \sup \left\{ |P(GH) - P(G)P(H)| : G \in \mathcal{F}_{-\infty}^k, H \in \mathcal{F}_{k+n}^\infty, k \in \mathbb{Z} \right\}.$$

The sequence $\{X_n(t), n \in \mathbb{Z}\}$ is called α -mixing if $\alpha(n) \rightarrow 0$ as $n \rightarrow \infty$. In [4], the author introduced modified versions of the mixing coefficient defined above. For the stochastic process $\{X_n(t), n \in \mathbb{Z}\}$, the modified α -mixing coefficient is defined by:

$$\alpha_m(n) = \sup_{\Pi_m} \sup \left\{ |P(GH) - P(G)P(H)| : G \in \mathcal{F}_{-\infty}^k(m), H \in \mathcal{F}_{k+n}^\infty(m), k \in \mathbb{Z} \right\}$$

where $\mathcal{F}_r^s(m)$ is the σ -algebra generated by the random vector $(\Pi_m X_r(t), \dots, \Pi_m X_s(t))$ and $\Pi_m: L_p[0,1] \rightarrow \mathbb{R}^m$ is a projective operator, i.e.,

$$\Pi_m X_j(t) = (X_j(t_1), \dots, X_j(t_m)), \quad t_j \in [0,1].$$

The sequence $\{X_n(t), n \in \mathbb{Z}\}$ is called α_m -mixing if $\alpha_m(n) \rightarrow 0$ as $n \rightarrow \infty$, for any fixed $m = 1, 2, \dots$. In general, α_m -mixing does not necessarily imply α -mixing.

Theorem 1 is established under the assumption that there exist real constants $u > 0$ and $0 < v < 1$ such that

$$\|T^j\| \leq uv^j, \quad j \geq 0.$$

Theorem 1. Let $\{X_n(t), n \in \mathbb{Z}\}$ be an AR(1)-process and $\{\varepsilon_n, n \in \mathbb{Z}\}$ be an α_m -mixing, strictly stationary, centered sequence of $L_p[0,1]$ -valued $1 \leq p \leq 2$ random variables satisfying $E\|\varepsilon_1\|^2 < \infty$. Assume that the following conditions hold for some $\delta > 0$

$$\sum_{n=1}^{\infty} (\alpha_m(n))^{\frac{\delta}{2+\delta}} < \infty, \quad m = 1, 2, \dots$$

$E|\varepsilon_1(t+h) - \varepsilon_1(t)|^{2+\delta} \leq f(h)$ for $0 \leq h < 1$, $0 \leq t \leq 1-h$, for some function $f(\cdot)$ such that $f(h) \rightarrow 0$ as $h \rightarrow 0$.

For all $t \in [0,1]$

$$E|\varepsilon_1(t)|^{2+\delta} < \infty,$$

$$\lim_{n \rightarrow \infty} E \left(\frac{1}{\sqrt{n}} \sum_{i=1}^n \varepsilon_i(t) \right)^2 > 0.$$

Then the following weak convergence holds

$$\frac{1}{\sqrt{n}} \sum_{i=1}^n (X_i - \mu) \Rightarrow (I - T)^{-1} N_K(t)$$

where $N_K(t)$ is $L_p[0,1]$ -valued Gaussian random variable with mean zero and covariance function

$$K(x, y) = \lim_{n \rightarrow \infty} \text{cov} \left(\frac{1}{\sqrt{n}} \sum_{i=1}^n \varepsilon_i(x), \frac{1}{\sqrt{n}} \sum_{i=1}^n \varepsilon_i(y) \right), \text{ where } x, y \in [0,1].$$

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R² DA ANIQLANGAN BA'ZI NOCHIZIQLI OPERATORLARNING QO'ZG'ALMAS NUQTALARI HAQIDA

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Annotatsiya. Mazkur ishda R^2 da aniqlangan ba'zi nochiziqli operatorlarning musbat qo'zg'almas nuqtalari, haqiqiy koeffitsiyentli ko'phadlarning musbat ildizlari yordamida tadqiq qilingan.

Biz $Q_k: R^2 \rightarrow R^2$ nochiziqli operatorni quyidagicha aniqlaylik:

$$Q_k(x, y) = \left(\sum_{i=0}^k C_k^i a_i x^{k-i} y^i, a_{k+1} x^k + \sum_{i=1}^k C_k^i a_{i-1} x^{k-i} y^i \right), \quad (k \in \mathbb{N} \setminus \{1\})$$

bu yerda $C_k^i = \frac{k!}{(k-i)!i!}$ (Binomial koeffitsiyent) va barcha $i \in \{1, 2, \dots, k\}$ lar uchun $a_i > 0$.

Mazkur ishda Q_k nochiziqli operatorning

$$R_{>}^2 = \{(x, y) \in R^2: x > 0, y > 0\}$$

dagi qo'zg'almas nuqtalarini o'rganish masalasi qaraladi. Qaralayotgan operator ajraluvchi va simmetrik yadroli Gammershteyn tipiga mansub integral tenglamalarni musbat yechimini topishda hamda Keli daraxtidagi translatsion-invariant Gibbs o'lchovlarini tasniflashda hosil bo'ladi ([1-3] ishlarga qarang).

Ushbu

$$P_{k+1}(\xi) = \sum_{j=1}^k C_k^j \left(\frac{k-2j+1}{k-j+1} \right) a_{k-j} \xi^{k-j+1} - a_{k+1}$$

$k+1$ darajali ko'phadni aniqlaylik.

Lemma. $P_{k+1}(\xi)$ ko'phad yagona musbat ildizga ega.

Teorema. Q_k operator

$$\left(\frac{1}{\left(\sum_{i=0}^k C_k^i a_i \xi_0^i \right)^{\frac{1}{k}}}, \frac{\xi_0}{\left(\sum_{i=0}^k C_k^i a_i \xi_0^i \right)^{\frac{1}{k}}} \right) \in R_{>}^2$$

qo'zg'almas nuqtaga ega bo'lishi uchun

$$\sum_{j=1}^k C_k^j \left(\frac{k-2j+1}{k-j+1} \right) a_{k-j} \xi^{k-j+1} - a_{k+1} = 0$$

tenglama $\xi_0 > 0$ yechimga ega bo'lishi zarur va yetarli.

Natija. Q_k operator yagona $(x_0, y_0) \in R_+^2$ qo'zg'almas nuqtaga ega.

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O'PKA RENTGEN TASVIRLARIDA ENERGIYAGA ASOSLANGAN OCHIQ DUNYO OBYEKT ANIQLASH USULI

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ANNOTATSIYA

Ushbu tezisda o'pka kasalliklariga oid rentgenogramlarda ma'lum va noma'lum kasallik o'choqlarini bir vaqtda aniqlash uchun YOLOv8s modeli ustiga post-hoc tarzda joriy etiladigan energiyaga asoslangan ochiq dunyo balli tizimi (Energy-based Open-World Score) taqdim etiladi. Tizim VinDr-CXR ma'lumotlar to'plamida o'qitilgan va JSRT to'plamida domenlararo baholanadi. Natijalar energiya balli tizimining noma'lum ob'ektlarni AUROC = 0.60–0.75 ko'rsatkichi bilan aniqlashga qodir ekanligini isbotlaydi.

Kalit so'zlar: o'pka saratoni, YOLOv8, ochiq dunyo aniqlash, energiya balli tizimi, OOD, VinDr-CXR, JSRT, domenlararo umumlantirish.

KIRISH

So'nggi yillarda sun'iy intellekt va chuqur o'rganish texnologiyalarining jadal rivojlanishi tibbiy tasvirlarni avtomatik tahlil qilish sohasida sezilarli yutuqlarga olib keldi. Ayniqsa, ko'krak qafasi rentgenogrammalarini tahlil qilishda konvolyutsion neyron tarmoqlari (CNN) va obyekt aniqlash modellaridan foydalanish diagnostika jarayonining tezligi va aniqligini oshirishga xizmat qilmoqda. Biroq amaldagi aksariyat chuqur o'rganish tizimlari “yopiq dunyo” (Closed-World Assumption) tamoyili asosida qurilgan bo'lib, bunda model o'qitish jarayonida faqat oldindan belgilangan sinflarni o'rganadi va test bosqichida ham faqat shu sinflar mavjud deb faraz qilinadi. Klinik amaliyotda esa bu taxmin doimo ham to'g'ri bo'lavermaydi, chunki real tibbiy muhitda model ilgari uchratmagan yangi patologiyalar, noodatij anatomik o'zgarishlar yoki boshqa taqsimotga mansub ma'lumotlar uchrashi tabiiy hol hisoblanadi.

Mazkur holat “taqsimotdan tashqari” (Out-of-Distribution, OOD) obyektlar muammosini yuzaga keltiradi. Agar model o'ziga noma'lum bo'lgan patologiyani mavjud sinflardan biriga

noto'g'ri tasniflash, bu klinik diagnostikada jiddiy xatoliklarga olib kelishi mumkin. Tibbiy diagnostika kabi yuqori mas'uliyat talab qiladigan sohalarida bunday noto'g'ri klassifikatsiyalar bemor xavfsizligiga salbiy ta'sir ko'rsatadi. Shu sababli zamonaviy sun'iy intellekt tizimlari nafaqat ma'lum sinflarni aniqlashi, balki noma'lum obyektlarni ham "unknown" sifatida ajrata olishi talab etiladi.

Ushbu muammoni hal etish maqsadida "Ochiq dunyo obyekt aniqlash" (Open World Object Detection — OWOD) paradigmasi taklif etilgan. OWOD yondashuvi modelga ikki xil vazifani bir vaqtning o'zida bajarish imkonini beradi: birinchisi — o'qitilgan sinflarni aniq aniqlash, ikkinchisi esa ilgari ko'rilmagan noma'lum obyektlarni alohida kategoriya sifatida belgilash. Bu esa tizimning moslashuvchanligini oshirib, real klinik muhitga yaqinlashtiradi. OWOD paradigmasi ayniqsa tibbiy tasvirlarda muhim ahamiyatga ega, chunki patologiyalar spektri doim kengayib boradi va barcha mumkin bo'lgan holatlarni trening ma'lumotlariga kiritish amaliy jihatdan imkonsizdir.

Mazkur tadqiqotning asosiy maqsadi — YOLOv8s modeli asosida sodda, hisoblash jihatidan samarali va amaliyotga mos post-hoc OWOD tizimini ishlab chiqish hamda uni domenlararo sharoitda sinovdan o'tkazishdan iborat. Tadqiqotda trening ma'lumotlari sifatida VinDr-CXR ma'lumotlar to'plamidan foydalaniladi, test bosqichida esa modelning umumlashuv qobiliyatini baholash maqsadida JSRT ma'lumotlar bazasida domenlararo tekshiruv amalga oshiriladi. Domenlararo tahlil modelning boshqa klinik markaz yoki boshqa turdagi tasvirlash sharoitlarida ham barqaror ishlash qobiliyatini aniqlash imkonini beradi.

Mavzu bo'yicha olib borilgan ilmiy tadqiqotlar OWOD va OOD aniqlash yo'nalishining dolzarbligini tasdiqlaydi. Liu va hammualliflar energiyaga asoslangan OOD aniqlash usulini taklif etib, model logit vektoridan hisoblangan energiya qiymati orqali noma'lum obyektlarni aniqlash mumkinligini ko'rsatganlar. Ularning yondashuvida energiya quyidagi formula orqali aniqlanadi:

$$E(x, i) = -\log \sum_{k=1}^K \exp(z_k(x, i)) \quad (1)$$

x — kiruvchi tasvir;

i — modeldagi ma'lum katak (bounding box yoki grid cell);

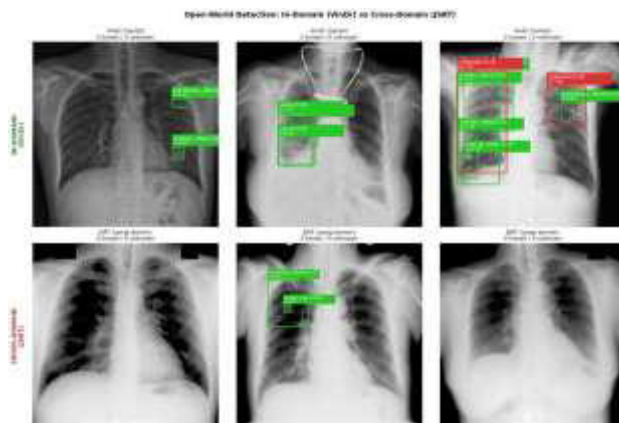
$z_k(x, i) - k$ — sinflar soni;

Logit — bu modelning "shu obyekt mana shu sinfga o'xshaydi" degan ichki bahosi.

Modelning optimal ajratish chegarasi validatsiya to'plamida kalibrovka qilindi. Bunda noto'g'ri musbat natijalar ulushi (FPR95) hamda AUROC ko'rsatkichlari birgalikda optimallashtirildi.

$$\tau^* = \arg \min_{\tau} [FPR_{95}(\tau) + \lambda \cdot (1 - AUROC(\tau))] \quad (2)$$

Mazkur optimallashtirish natijasida hosil qilingan τ^* chegara qiymati obyektlarni "ma'lum" va "noma'lum" sinflarga ajratishda asosiy mezon sifatida ishlatildi. Agar energiya qiymati $E < \tau^*$ bo'lsa, obyekt ma'lum sinf sifatida qabul qilinib yashil ramka bilan belgilandi. Aksincha, $E \geq \tau^*$ bo'lgan hollarda obyekt noma'lum deb topilib qizil ramka bilan ajratildi. Natijani quyidagi rasmlar orqali ko'rish mumkin.



1-rasm. VinDr (yuqori) va JSRT (quyi) tasvirlarida aniqlash: yashil = ma'lum, qizil = noma'lum ($E \geq \tau^*$)

VinDr va JSRT ma'lumotlar to'plamlaridagi aniqlash natijalari tasvirlangan. Yuqori qismdagi VinDr tasvirlarida model ma'lum patologiyalarni yuqori aniqlik bilan yashil ramkalar yordamida belgilagan. Pastki qismdagi JSRT tasvirlarida esa ayrim anomal hududlar uchun energiya qiymati chegaradan yuqori bo'lgani sababli ular qizil ramka bilan ko'rsatilgan. Bu holat modelning treningda uchramagan obyektlarni ajratib ko'rsatish qobiliyatini namoyon etadi.

Tadqiqot davomida domenlararo tafovutlarni kamaytirish maqsadida JSRT tasvirlariga histogram matching usuli qo'llanildi. Ushbu moslashtirish natijasida tasvirlarning yorqinlik va kontrast ko'rsatkichlari VinDr ma'lumotlariga yaqinlashtirildi. Natijada modelning recall ko'rsatkichi 5–10 foiz punktga oshgani aniqlandi. Olingan natijalar energiyaga asoslangan ochiq toifali aniqlash yondashuvi hamda domen moslashtirish usullari tibbiy tasvirlarda noma'lum patologiyalarni aniqlash samaradorligini sezilarli ravishda yaxshilashini ko'rsatdi.

Xulosa: Taqdim etilgan post-hoc energiya balli tizimi YOLOv8s modeliga hech qanday arxitektura o'zgartirishsiz qo'llanildi. Tizim klinik «ochiq dunyo» sharoitida ma'lum o'choqlarni aniqlab ($mAP@50 = 0.15–0.28$), noma'lum ob'ektlarni $E \geq \tau^*$ mezoni bo'yicha bayroqchalar bilan belgiladi ($AUROC = 0.60–0.75$). Domenlararo sinovda (VinDr $\rightarrow$ JSRT) gistogramma moslashtirish recall ni +5–10 pp ga oshirdi. Natijalar tizimning cheklangan hisoblash resurslari (RTX 4060, 8 GB VRAM) sharoitida ham to'liq ishlash qobiliyatini tasdiqlaydi.

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TIBBIY TASVIRLARDA HALOKATLI UNUTISHGA QARSHI UZLUKSIZ O'RGANISH: REPLAY VA LOGIT DISTILLYATSIYA

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Annotatsiya

Ushbu tezisda o'pka saratoniga oid rentgenogrammlarda YOLOv8s modelini uch bosqichli ketma-ket o'qitishda yuzaga keladigan «halokatli unutish» (Catastrophic Forgetting) muammosini bartaraf etishga mo'ljallangan Replay va Logit Distillyatsiya (Knowledge Distillation, KD)

kombinatsiyasi taqdim etiladi. Eksperimental natijalar 1-bosqich sinflarining mAP@50 ko'rsatkichi uch bosqichli o'qitish davomida 0.35 dan 0.47 gacha oshganligini — ya'ni halokatli unutish sodir bo'lmaganini — tasdiqlaydi.

Kalit so'zlar: uzluksiz o'rganish, halokatli unutish, replay, logit distillyatsiya, YOLOv8, ko'p bosqichli o'qitish, VinDr-CXR, o'pka saratoni

KIRISH

Zamonaviy sun'iy intellekt va chuqur o'qitish (Deep Learning) tizimlari tibbiyot, iqtisodiyot va avtonom boshqaruv kabi ko'plab sohalarda inqilobiy o'zgarishlarni amalga oshirmoqda. Biroq, biologik neyron tizimlaridan farqli o'laroq, sun'iy neyron tarmoqlari yangi ma'lumotlarni ketma-ket (sequential) o'rganish jarayonida jiddiy muammoga duch keladi. Yangi vazifa yoki ma'lumotlar to'plami bilan o'qitish jarayonida modelning avval olingan bilimlarni keskin va butunlay yo'qotishi hodisasi ilmiy adabiyotlarda «**halokatli unutish**» (**Catastrophic Forgetting**) deb ataladi [1]. Ushbu muammo sun'iy intellektning **uzluksiz o'rganish (Continual Learning)** yoki **umrbod o'rganish (Lifelong Learning)** qobiliyatini cheklovchi eng asosiy to'siq hisoblanadi.

Tibbiy diagnostika va raqamli sog'liqni saqlash tizimlarida halokatli unutish muammosi shunchaki nazariy kamchilik emas, balki inson hayotiga bevosita daxldor bo'lgan kritik xavfdir. Masalan, onkologik kasalliklarni tasvirlar (KT, MRT, rentgen) orqali klassifikatsiya qiluvchi tizim dastlab faqat o'pka saratonining muayyan turlarini aniqlashga o'rgatilgan bo'lsin. Vaqt o'tishi bilan tizimga saratonning yangi sinflari yoki bosqichma-bosqich aniqlangan yangi patologiyalar ketma-ket qo'shib boriladi. Agar ushbu bosqichda halokatli unutish yuz bersa, model yangi sinflarni a'lo darajada o'rgangani holda, avvalgi sinflarni aniqlash sifatini keskin tushirib yuboradi. Bu esa klinikalarda noto'g'ri tashxis qo'yilishiga, shifokorlarning tizimga bo'lgan ishonchi (clinical trust) yo'qolishiga va eng yomoni, bemorlar hayotining xavf ostida qolishiga olib keladi.

Uzluksiz o'rganish muammosini hal etish uchun amaliyotda bir qator usullar taklif etilgan. Bular qatoriga parametrlarning muhimligini baholovchi muntazamlashtirish (regularization) usullari (masalan, EWC [2]), model arxitekturasini dinamik kengaytiruvchi yondashuvlar va o'tgan ma'lumotlarni xotirada saqlashga asoslangan dinamik tizimlar (LwF [3], iCaRL [4]) kiradi. Biroq, ushbu metodlarning aksariyati yoki model parametrlarini haddan tashqari cheklab qo'yadi, yoki tarmoq arxitekturasini murakkablashtirib, hisoblash resurslariga (VRAM, CPU) bo'lgan talabni geometrik progressiyada oshiradi.

ADABIYOTLAR TAHLILI (LITERATURE REVIEW)

Uzluksiz o'rganish muammosi va uning negizida yotgan halokatli unutish fenomeni ilk bor 1989-yilda McCloskey va Cohen [1] tomonidan sun'iy neyron tarmoqlarining tabiati o'rganilayotganda aniqlangan va tavsiflangan. Muammoni hal qilish uchun yillar davomida uchta asosiy yondashuv rivojlandi: regularizatsiya (regularization-based), xotira yoki qayta ko'rish (replay-based) va arxitekturaviy (architectural-based) usullar.

Regularizatsiya yo'nalishida Kirkpatrick va boshqalar [2] tomonidan taklif etilgan **Elastic Weight Consolidation (EWC)** usuli muhim o'rin tutadi. EWC usulida modelning avvalgi vazifalar uchun eng muhim bo'lgan parametrlari (vaznlari) Fisher axborot matritsasi (Fisher Information Matrix) yordamida aniqlanadi va yangi vazifalarni o'rganishda ushbu muhim vaznlarning keskin o'zgarishi cheklanadi.

Muqobil ravishda, Li va Hoiem [3] tomonidan taqdim etilgan "**Learning without Forgetting**" (**LwF**) usuli regularizatsiyani bilimlarni distillyatsiyalash (Knowledge Distillation) orqali amalga oshiradi. Bunda modelning eski versiyasi "O'qituvchi" (Teacher), yangi versiyasi esa "Talaba" (Student) vazifasini bajaradi va yangi ma'lumotlar ustida ishlaganda eski modelning chiqish ehtimolliklari saqlab qolinishiga harakat qilinadi.

Rebuffi va boshqalar [4] o'zlarining **iCaRL (Incremental Classifier and Representation Learning)** tizimida xotira elementlarini (exemplars) saqlash va distillyatsiya yo'qotish funksiyasini muvaffaqiyatli birlashtirib, tasvirlarni sinflashda yuqori natijalarga erishdilar.

Ushbu tadqiqot ishi yuqoridagi tajribalarga tayangan holda, replay va logit darajasidagi distillyatsiya mexanizmlarini birlashtiradi. iCaRL va LwF yondashuvlaridan farqli o'laroq, ushbu

usul tibbiy ob'ektlarni lokalizatsiya qilish va aniqlash (Object Detection) vazifasiga, xususan, YOLOv8s detektoriga moslashtirilgan holda tatbiq etilgan.

Parallel Ishlovchi Mexanizmlar

Har bir ketma-ket bosqichda modelning halokatli unutishga chidamliligini ta'minlash uchun ikkita asosiy mexanizm parallel ravishda ishga tushiriladi:

1.Replay (Namunaviy qayta eslash mexanizmi): Avvalgi bosqichlarda o'rganilgan ma'lumotlar to'plamidan eng xarakterli k ta namunaviy tasvirlar (exemplars) maxsus xotira buferida saqlanadi. Yangi bosqich ma'lumotlari kelganda, ushbu eski namunalar yangi ma'lumotlar bilan minipartiyalarga (mini-batches) teng taqsimotda aralashtiriladi.

2.Logit Knowledge Distillation (Logit darajasidagi bilimlarni distillyatsiyalash): Model yangi sinfni o'rganishdan oldin uning nusxasi olinadi va u "muzlatilgan" o'qituvchi model ($f_{teacher}$) vazifasini o'taydi. Yangi o'qitilayotgan talaba modeli ($f_{student}$) tasvirlarni qayta ishlashda nafaqat ob'ektni aniqlashi, balki uning oxirgi qatlam chiqishlari (logits) muzlatilgan model chiqishlariga maksimal darajada o'xshash bo'lishi majburlanadi.

2.2. Matematik Model va Yo'qotish Funktsiyasi (Loss Function)

Modelni optimallashtirish uchun umumiy yo'qotish funksiyasi ob'ektni aniqlash yo'qotishi va distillyatsiya yo'qotishining kompozitsiyasi ko'rinishida shakllantiriladi:

$$\mathcal{L}_{total} = \mathcal{L}_{del} + \alpha \cdot \mathcal{L}_{KD}$$

Bu yerda:

$\mathcal{L}_{det}$ — YOLOv8s standart ob'ektni aniqlash (baxslash, klassifikatsiya va lokalizatsiya) loss funksiyasi;

$\mathcal{L}_{KD}$ — Logit distillyatsiya yo'qotish funksiyasi;

α — distillyatsiya muvozanatini boshqaruvchi giperparametr bo'lib, eksperimentlarda $\alpha = 0.5$ deb belgilandi.

Logit distillyatsiya yo'qotish funksiyasi Kullback-Leibler (KL) divergatsiyasi orqali hisoblanadi va "yumshatish temperaturasi" (T) giperparametridan foydalaniladi:

$$\mathcal{L}_{KD} = \frac{1}{N} \sum_i KL \left(\left(\sigma \frac{z_i^s}{T} \right) \parallel \left(\sigma \frac{z_i^t}{T} \right) \right), T \in \{2, 3, 4\}$$

Bu yerda z_i^s va z_i^t mos ravishda talaba va o'qituvchi modellarining logit chiqishlari, σ esa Softmax funksiyasidir. Temperaturaning kiritilishi modelga sinflar o'rtasidagi yashirin korrelyatsiyalarni (dark knowledge) yaxshiroq o'zlashtirish imkonini beradi.

III. ASOSIY QISM VA NATIJALAR TAHLILI (RESULTS & DISCUSSION)

Eksperimentlar NVIDIA RTX 4060 (8 GB VRAM) video-kartasiga ega bo'lgan hisoblash muhitida olib borildi. Taklif etilgan yondashuv samaradorligini baholash uchun u "Xom fine-tuning" (hech qanday CL usulisiz to'g'ridan-to'g'ri yangi ma'lumotga moslashtirish) va "Faqat Replay" yondashuvlari bilan taqqoslandi. Baholash mezoni sifatida ob'ektni aniqlashdagi mAP@50 (Mean Average Precision) ko'rsatkichidan foydalanildi.

2-jadval. Uzluksiz o'rganish usullarining taqqoslash natijalari (1-bosqich sinflari uchun dinamika)

Yondashuv turi	B1 bosqichidagi mAP@50	B3 bosqichidagi mAP@50	Ko'rsatkichning o'zgarishi
Xom fine-tuning (Baseline)	0.35	~0.15 – 0.20	↓ –15 pp (Kuchsizlanish)
Faqat Replay	0.35	~0.32 – 0.38	↓ –3 pp (Barqarorlikka yaqin)
Replay + KD [Taklif etilgan usul]	0.35	0.47	↑ +12 pp (Ijobiy o'sish)

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FRAKTAL NAZARIYASI ASOSIDA MUSIQA KOMPOZITSIYASINI GENERATSIYA QILISH USULLARI

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Annotatsiya. Ushbu maqolada fraktal nazariyasi asosida musiqa kompozitsiyasini generatsiya qilish usullari tahlil qilingan. Fraktallarning o‘z-o‘ziga o‘xshashlik, rekursiya, iterativ qurilish va strukturaviy murakkablik kabi xususiyatlarining musiqiy kompozitsiya yaratish jarayonidagi o‘rni yoritilgan. Musiqa generatsiyasida rekursiv generatsiya, iteratsion matematik ketma-ketliklar, L-tizimlar, grammatik modellar hamda geometrik fraktallardan musiqiy xaritalash usullarining imkoniyatlari ko‘rib chiqilgan.

Kalit so‘zlar: fraktal nazariya, musiqa kompozitsiyasi, algoritmik kompozitsiya, generativ musiqa, rekursiya, iteratsion modellar, L-tizimlar, geometrik fraktallar.

Kirish

Axborot texnologiyalari, raqamli san‘at va intellektual algoritmlarning jadal rivojlanishi musiqa yaratish jarayoniga ham sezilarli ta‘sir ko‘rsatmoqda. An‘anaviy kompozitorlik tajribasi bilan bir qatorda algoritmik kompozitsiya, kompyuter yordamida musiqa yaratish, generativ san‘at va sun‘iy intellekt asosidagi yondashuvlar keng qo‘llanilmoqda. Shu nuqtai nazardan, murakkab tizimlar nazariyasi va fraktal geometriya imkoniyatlaridan musiqa yaratishda foydalanish alohida ilmiy qiziqish uyg‘otadi.

Fraktal nazariyasi tabiiy va sun‘iy tizimlardagi murakkab, ammo ichki qonuniyatga ega strukturalarni tavsiflash imkonini beradi. Fraktallarning asosiy xususiyati - o‘z-o‘ziga o‘xshashlik, ya‘ni butunning alohida qismlarida uning umumiy tuzilishiga xos belgilar takrorlanishidir. Musiqada ham shu kabi hodisalarni kuzatish mumkin: motivning takrorlanishi, ritmik qoliplarning

turli masshtablarda qayta paydo bo'lishi, melodik harakatlarning rekursiv rivojlanishi, shakl va bo'limlar o'rtasidagi strukturaviy uyg'unlik shular jumlasidandir.

Fraktal musiqa - fraktal geometriyaning muayyan turi tamoyillari va amaliy qo'llanishlariga asoslanib yaratilgan, yakunda fraktalsimon tuzilmani namoyon etuvchi musiqiy kompozitsiyadir. Mavjud fraktal musiqalarning katta qismi kompyuter yordamida yaratiladi va matematik algoritmlarni qo'llash natijasida hosil bo'ladi. Biroq fraktallar musiqada turli yo'llar bilan tasavvur qilinadi, yaratiladi va ifodalanadi.

Ularning barchasiga xos umumiy jihat shundaki, kompozitsiyaning fraktal tabiatini belgilovchi asosiy sifat - o'z-o'ziga o'xshashlikning ko'p darajali shaklda mavjudligidir. Ya'ni butun tuzilma uning kichik qismida, kichik qism esa butun tuzilmaning xususiyatlarida aks etadi.

Musiqa kompozitsiyasini generatsiya qilishda fraktal nazariyasidan foydalanish murakkab, estetik jihatdan uyg'un va mantiqan yaxlit musiqiy strukturalarni hosil qilishga yordam beradi. Ayniqsa, rekursiv algoritmlar, iteratsion funksiyalar va fraktal ketma-ketliklar yordamida melodiya, ritm va tembr qatlamlarini yaratish kompyuter musiqasi yo'nalishida muhim tadqiqot yo'nalishlaridan biri hisoblanadi.

Fraktal nazariyasi matematikada murakkab geometrik strukturalarni tavsiflash uchun shakllangan bo'lib, keyinchalik fizika, biologiya, iqtisodiyot, signal jarayonlari va san'at sohalarida ham qo'llanila boshladi. Fraktal obyektlar odatda quyidagi xususiyatlarga ega bo'ladi:

- o'z-o'ziga o'xshashlik;
- rekursiv yoki iterativ qurilish;
- murakkablikning oddiy qoidalaridan kelib chiqishi;
- cheksiz darajadagi strukturalashuv imkoniyatidir.

Musiqiy kompozitsiyada bu xususiyatlar melodik motivlarning turli balandlik yoki vaqt masshtablarida qayta paydo bo'lishi, ritmik naqshlarning ko'payishi, kompozitsion shaklning kichik bo'limlarda ham o'z aksini topishi orqali namoyon bo'ladi. Demak, fraktal yondashuv musiqa yaratishda nafaqat matematik asos, balki badiiy strukturalash usuli sifatida ham xizmat qiladi.

Fraktal nazariyasiga asoslangan musiqa generatsiyasida bir nechta usullar qo'llaniladi.

Birinchi usul - rekursiv generatsiyadir. Bunda boshlang'ich melodik yoki ritmik motiv tanlanadi va u ma'lum transformatsiyalar orqali qayta-qayta hosil qilinadi. Masalan, motivning intervallarini saqlagan holda boshqa balandlikka ko'chirish, ritmik davomiylikni kichraytirish yoki kattalashtirish, teskari aylantirish, fragmentlash kabi amallar bajariladi. Natijada kompozitsiyada yaxlitlik saqlanadi, lekin takrorlanish zerikarli emas, balki rivojlanayotgan shaklga ega bo'ladi.

Ikkinchi usul - iteratsion matematik ketma-ketliklar asosida generatsiya. Masalan, sonli ketma-ketliklar musiqiy balandliklarga, ritmik uzunliklarga yoki dinamika qiymatlariga moslashtiriladi. Fraktal funksiya yoki xaritalar yordamida hosil qilingan sonlar musiqiy parametrlar bilan bog'lanib, noodatiy, ammo ichki qonuniyatga ega musiqiy oqim hosil qiladi.

Uchinchi usul - L-tizimlar va grammatik modellardir. Bunday yondashuvlarda boshlang'ich belgilardan iborat ketma-ketlik beriladi va u qayta yozish qoidolari asosida kengaytiriladi. Olingan simvolik ketma-ketlik keyinchalik notalar, pauzalar, akkordlar yoki artikulyatsiya belgilari bilan bog'lanadi. Ushbu usul fraktal o'sish mantig'iga yaqin bo'lib, tabiiy tuzilmalar bilan musiqiy shakllar o'rtasida qiziqarli analogiyalarni yuzaga keltiradi.

To'rtinchi usul - geometrik fraktallardan musiqiy xaritalashdir. Masalan, Mandelbrot to'plami yoki Koch egri chizig'i kabi fraktal shakllarning koordinatalari vaqt va balandlikka moslashtirilishi mumkin. Natijada grafik strukturadan musiqiy material hosil qilinadi. Bu usul ko'proq eksperimental va elektroakustik musiqa yo'nalishlarida samarali hisoblanadi.

Fraktal nazariyasi asosida musiqa kompozitsiyasini generatsiya qilish usullari kelajakda bir nechta yo'nalishlarda samarali qo'llanishi mumkin:

- kompyuter yordamida kompozitsiya yaratish tizimlarida;

- sun'iy intellekt bilan integratsiyalashgan generativ musiqa platformalarida;
- ta'lim jarayonida algoritmik kompozitsiyani o'rgatishda;
- multimedia, o'yin industriyasi va interaktiv san'at loyihalarida;
- terapiya va meditatsiya uchun moslashuvchan generativ musiqa tizimlarida.

Ayniqsa, fraktal modellarni neyron tarmoqlar, evolyutsion algoritmlar va mashinali o'qitish usullari bilan birlashtirish kelgusida yanada murakkab, moslashuvchan va estetik jihatdan boy musiqa yaratish imkonini beradi.

Xulosa. Fraktal nazariyasi asosida musiqa kompozitsiyasini generatsiya qilish usullari zamonaviy algoritmik kompozitsiyaning muhim yo'nalishlaridan biridir. Fraktallarning o'z-o'ziga o'xshashlik, rekursiya va strukturaviy murakkablik kabi xususiyatlari musiqada melodik, ritmik va formal qurilmalarni samarali modellashtirish imkonini beradi. Bunday yondashuv musiqiy materialni avtomatik yaratish, struktura yaxlitligini saqlash hamda kompozitsion xilma-xillikni yuzaga keltirishda muhim ahamiyatga ega.

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GRAPH-BASED TOPOLOGICAL BLENDSHAPE REPRESENTATION FOR INTERPRETABLE AFFECTIVE COMPUTING ARCHITECTURES

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Abstract: This study proposes an explainable spatial-temporal graph neural network (ST-GNN) for real-time cognitive and behavioral state monitoring using facial blendshape graph structures. The model achieves robust performance under occlusions and head rotations with a macro F1-score of 0.942 and 112.5 ms latency. An integrated SHAP mechanism provides transparent and interpretable decision analysis for safety-critical applications.

Keywords: Graph Neural Networks, Spatial-Temporal Convolution, Blendshape Modeling, Explainable Artificial Intelligence (XAI), Shapley Values, Cognitive Monitoring.

Introduction

To standardize the computational tracking of facial movements, contemporary architectures frequently deploy multi-dimensional blendshape animation configurations and the structural classifications of the Facial Action Coding System (FACS). Blendshapes represent localized facial muscle movements as digitized weight vectors, effectively compressing dense structural geometric points into a standardized numerical array. While this linear compression enables efficient pipeline integration, standard architectures treat individual blendshape activation levels as entirely independent variables. In reality, human facial musculature functions as a deeply integrated, interconnected system where the movement of a specific muscle group directly constraints or

amplifies adjacent regions. Neglecting these topological dependencies significantly limits the model's performance when encountering subtle, compound, or heavily occluded micro-expressions.

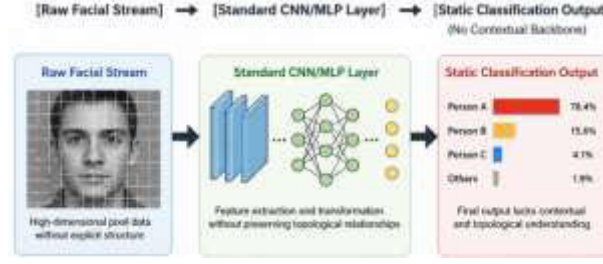


Fig.1. Conventional CNN/MLP facial processing architecture

Furthermore, legacy deep learning solutions applied to affective computing, such as Convolutional Neural Networks (CNNs) and standard Multi-Layer Perceptrons (MLPs), treat facial expression tracking through a localized, pixel-centric or flat-vector paradigm. These models excel at identifying prominent spatial features under ideal lighting conditions but degrade severely when faced with off-axis head rotations, structural lighting changes, or subtle personal variations.

Methods

To transition facial expression analysis from rigid Euclidean pixel spaces to an anatomically grounded geometric paradigm, the human face is modeled as a dynamic, non-Euclidean graph topology. We define this structure as a directional, weighted spatial-temporal graph denoted by $G=(V,E,W)$, where V represents the finite set of localized blendshape nodes, E denotes the set of structural edges representing physical-anatomical dependencies, and W represents the dynamic weight matrix modulating connection strengths. Each node $v_i \in V$ corresponds directly to a specific facial blendshape channel or Action Unit (AU) derived from front-end performance capture sensors. The instantaneous state of node v_i at a discrete time frame t is represented by a scalar weight vector $x_i^{(t)} \in [0, 1]$, quantifying the activation intensity of that localized muscle group.

Unlike baseline multi-layer architectures that treat blendshape activations as disconnected, independent inputs, the edge set E explicitly restricts feature propagation based on facial musculature realities. An edge $e_{ij} = (v_i, v_j)$ is established within the graph configuration if and only if a documented anatomical co-activation or structural constraint exists between muscle group i and muscle group j . For instance, the activation of the *Inner Brow Raiser* node is topologically linked via adjacent edges to the *Outer Brow Raiser* and *Nasalis* nodes to mimic realistic physical skin deformations. By bounding feature transformations within this custom topological skeleton, the model filters out random pixel noise, establishing a robust geometric foundation that preserves spatial continuity during continuous behavioral monitoring sessions.

The underlying structural interconnectivity of the facial graph is mathematically governed by a specialized, trainable adjacency matrix $A \in \mathbb{R}^{|V| \times |V|}$. Rather than enforcing a static, binary connectivity pattern, the entries A_{ij} are continuously optimized via a localized self-attention routing layer. To preserve basic structural stability while allowing for individual structural variance, the matrix is initialized by combining an immutable anatomical template matrix A_{base} with a dynamic, data-driven displacement matrix A_{adapt} , such that:

$$A = A_{base} + A_{adapt} \quad (1)$$

The static matrix A_{base} dictates the fundamental geometric limits of human facial movement, while A_{adapt} updates during active inference loops to accommodate individual user movement variations.

To ensure numerical stability and prevent gradient explosions across multi-layered graph structures during backpropagation, the finalized adjacency matrix undergoes symmetrical normalization. We apply a self-loop extension by adding the identity matrix I_n to A , yielding the augmented matrix $\hat{A} = A + I_n$. The corresponding diagonal degree matrix $D \in \mathbb{R}^{|V| \times |V|}$ is calculated where each diagonal entry represents the sum of the row elements, expressed mathematically as

$\hat{D}_{ii} = \sum_j \tilde{A}_{ij}$. The symmetrically normalized spatial convolution matrix is subsequently derived using the inverse square root transformation of the degree matrix, formulated as:

$$\tilde{A} = \tilde{D}^{-\frac{1}{2}} \tilde{A} \tilde{D}^{-\frac{1}{2}} \quad (2)$$

This normalized structural tensor forms the mathematical backbone for all subsequent spatial message-passing actions across the facial network surface.

Feature extraction across the irregular facial surface is executed using multi-layered Spatial Graph Convolutional Networks (SGCN). Within these geometric computing layers, node states are iteratively updated by aggregating descriptive parameters from immediate neighborhood boundaries. Let $H^{(l)} \in \mathbb{R}^{|V| \times d(l)}$ denote the complete feature activation matrix of the graph at the l -th convolutional layer, where $d(l)$ represents the hidden dimensionality of the node attributes, and $H^{(0)}$ is initialized directly from the input weight vectors $X^{(t)}$. The forward propagation behavior that governs structural message transfers across adjacent muscle networks is explicitly defined by the following tensor equation:

$$H^{(l+1)} = \sigma \left(\tilde{A} H^{(l)} W^{(l)} \right) \quad (3)$$

where $W^{(l)} \in \mathbb{R}^{d(l) \times d(l+1)}$ represents the parameterizable weight transformation matrix of the l -th neural layer, and $\sigma(\cdot)$ denotes a non-linear activation function, specifically the LeakyReLU operator set with a negative slope coefficient of 0.02.

Through this layer configuration, the spatial convolution operation computes a localized linear combination of feature vectors within a node's immediate neighborhood, followed by a trainable linear projection. As the message-passing depth scales across sequential layers ($l=1,2,\dots,L$), individual nodes incrementally absorb structural context from higher-order neighborhoods. A third-tier convolution layer ($L=3$), for example, allows localized eye region nodes to evaluate global mouth and jaw motions simultaneously. This global spatial context ensures that individual blendshape anomalies caused by tracking drops or sudden lighting changes are smoothed out by neighboring node states, boosting overall tracking resilience.

To track continuous emotional shifts accurately, the spatial graph convolutional layers are directly coupled with an autoregressive temporal routing mechanism. Human expressions are fundamentally time-dependent sequences where the velocity and acceleration of muscle deformations carry vital cognitive indicators. To capture these temporal signatures without destroying the spatial graph architecture, we implement Spatial-Temporal Graph Convolutional blocks (ST-GCN). Temporal edges are established across continuous time frames, linking the exact same node ID ($v_i^t \rightarrow v_i^{(t+1)}$) across a sliding temporal window of size $T=12$ frames. This creates a unified spatial-temporal network grid where graph convolutions are simultaneously executed across both geometric and chronological dimensions.

The temporal integration layer applies a 1D structural convolution along the time dimension of the node feature matrix, updating the network states using a parameterized kernel size $K_t=3$. This architecture allows the model to compute localized temporal derivatives for each blendshape channel, isolating macro-expression acceleration boundaries from background muscle twitching. By avoiding legacy recurrent configurations like standard LSTMs, our ST-GCN block processes large data blocks in parallel, maintaining stable throughput speeds under intense concurrent session streams. The resulting spatial-temporal node embeddings capture the true physical velocity of facial expressions, preventing classification errors during rapid micro-expressions.

A core priority of this methodology is eliminating black-box unreliability by establishing an embedded Explainable AI (XAI) validation layer. To achieve absolute algorithmic accountability, the framework maps localized feature attributions directly onto the graph's node-edge architecture using an integrated Shapley Additive explanation protocol. For every discrete cognitive classification output Y^c , the exact contribution score (Shapley Value ϕ_i) of each individual blendshape node $v_i \in V$ is derived analytically. The mathematical attribution function allocates

importance values across the network based on how much the prediction shifts when specific node connections are removed, computed via the following marginal contribution formula:

$$\phi_i(Y^c) = \sum_{S \subseteq V \setminus \{v_i\}} \frac{|S|!(|V|-|S|-1)!}{|V|!} [f_c(S \cup \{v_i\}) - f_c(S)] \quad (4)$$

where S represents a subset of active blendshape nodes, $|V|$ is the total node cardinality, and $f_c(S)$ denotes the conditional prediction score for target cognitive state c when evaluated using only the node configurations restricted to subset S .

Because the underlying model architecture propagates information along explicit, normalized edge paths ($\hat{A}$), these calculated Shapley values correspond directly to real physical adjustments on the user's face. The framework aggregates these nodal attribution indices to output an instantaneous transparency matrix for every inference cycle. If the system diagnoses an operator as "severely fatigued," the system does not simply output an unverified classification token. Instead, it generates a clear, readable node activation map showing exactly which blendshape paths (e.g., increased eye-closure weights coupled with specific eyebrow drops) drove that diagnosis. This explicit verification mechanism eliminates machine hallucination risks, allowing the platform to be safely deployed within high-stakes telemetry and industrial safety monitoring environments.

Following the final spatial-temporal convolution block, the enriched graph matrix is passed through a Global Generalized Pooling layer to collapse the non-Euclidean structure into a dense, flat classification vector. We utilize a hybrid pooling strategy that combines Global Average Pooling (GAP) and Global Max Pooling (GMP) to preserve both average background trends and sharp peak muscle activations across the face framework. The resulting pooled topology vector is routed into a fully connected linear layer capped with a Softmax activation function to generate a stable probability distribution over the target cognitive and behavioral state classes.

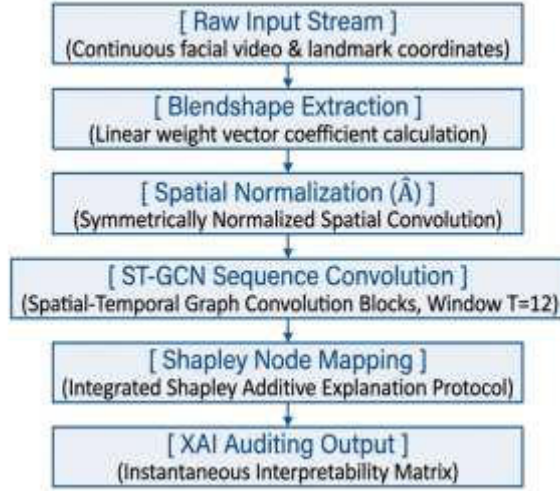


Fig. 2. Spatial-Temporal GNN Methodology Pipeline

Model optimization is achieved by minimizing a regularized Categorical Cross-Entropy loss function via the AdamW optimizer. To ensure that the network prioritizes structural consistency and penalizes erratic node transitions, a custom topological regularization term L_{topo} is appended to the standard objective function. The total training loss L_{total} is minimized over the parameter space according to the following equation:

$$L_{total} = -\frac{1}{N} \sum_{n=1}^N \sum_{c=1}^C y_{nc} \log(\hat{y}_{nc}) + \lambda \sum_{e_{ij} \in E} \|h_i - h_j\|_2^2 \quad (5)$$

where y_{nc} represents the true expert-verified label, $\hat{y}_{nc}$ is the predicted probability score, λ is a hyperparameter balancing coefficient set to 0.005, and the second term penalizes sharp feature variance between anatomically linked graph nodes h_i, h_j . This dual-optimization framework

guarantees that our model maintains high classification accuracy while adhering strictly to the biological realities of human facial

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НАСТРОЙКА РЕКУРРЕНТНОГО СЕТИ ЭЛМАНА

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Аннотация: В статье рассматривается использование простое рекуррентное сеть Элмана. Приведены входные и выходные параметры нейронных сетей, метод решения задачи. Представлена схема последовательный процесс генерации.

В задачах идентификации взаимосвязей между технологическими параметрами объектов автоматизированного управления используются возможности нейронных сетей. Одной из важных проблем, рассматриваемых в таких задачах идентификации, является выбор архитектуры нейронной сети моделируемого динамического объекта [1,2].

Для анализа и обработки последовательностей чаще используются рекуррентные нейросети, способные помнить (в теории) весь исторический контекст из предыдущих наблюдений и учитывать его вычислительно эффективно.

Для этого используется скрытое состояние $h_t \in \mathcal{R}^{D_h}$, хранящее контекст из всех ранее виденных наблюдений. Прогноз строится, учитывая не только текущее наблюдение x_t , но и h_t , что обеспечивает зависимость прогноза от истории:

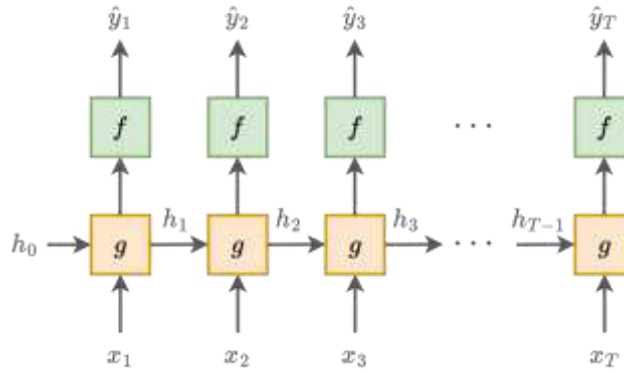
$$\hat{y}_t = f(x_t, h_t)$$

$\hat{y}_t$ часто не является итоговым прогнозом, а представляет собой лишь промежуточный эмбединг, по которому уже строится итоговый прогноз (применяя к нему многослойный персептрон или другую модель).

Само скрытое состояние пересчитывается на каждом шаге обработки последовательности рекуррентно по текущему наблюдению и своему значению на предыдущем шаге обработки:

$$h_t = g(x_t, h_{t-1}), \quad t = 1, 2, 3 \dots$$

Последовательный процесс генерации прогнозов $\hat{y}_1, \hat{y}_2, \dots, \hat{y}_T$ по входам $x_1, x_2, \dots, x_T$ и скрытым состояниям графически представляется следующим образом:



При этом $h_0 \in \mathbb{R}^{D_h}$ - тоже параметр сети, который можно задавать вектором из нулей или настраивать по данным.

Если разворачивать зависимость рекуррентной сети:

$$\begin{aligned}\hat{y}_t &= f(h_t) = f(g(x_t, h_{t-1})) = f(g(x_t, g(x_{t-1}, h_{t-2}))) = \\ &= f(g(x_t, g(x_{t-1}, g(x_{t-2}, h_{t-3})))) = \dots = F(x_t, x_{t-1}, \dots, x_1, h_0)\end{aligned}$$

то можно увидеть, что $\hat{y}_t$ зависит от всех ранее виденных наблюдений $x_t, x_{t-1}, \dots, x_1$ и строится многократным применением одних и тех же преобразований, $g(\cdot), f(\cdot)$ просто применённых к различным входным данным.

Таким образом, рекуррентная сеть - это обычная многослойная сеть, имеющая на каждом слое одинаковые параметры, а число слоёв совпадает с номером обрабатываемого элемента последовательности t . То есть для длинного входа эта сеть может содержать очень большое число слоёв.

Из-за того, что параметры сети на каждом слое одни и те же, настройка сети довольно неустойчива и имеет тенденцию скатываться в одну из крайностей:

- сеть экспоненциально быстро забывает историю (проблема затухающих градиентов);
- сеть экспоненциально быстро увеличивает вклад дальних наблюдений в прогноз, вследствие чего прогноз и настройка весов ведут себя неустойчиво (проблема взрывающихся градиентов).

Для решения первой проблемы используются специальные архитектуры, такие как GRU и LSTM.

Для решения второй используется обрезка градиентов (gradient clipping) по абсолютному или относительному значению.

Простейшей рекуррентной сетью является сеть Элмана [3]:

$$\begin{aligned}h_t &= g(W_{xh}x_t + W_{hh}h_{t-1} + b_h), \\ \hat{y}_t &= f(W_{hy}h_t + b_y),\end{aligned}$$

где: $g(\cdot), f(\cdot)$ - некоторые функции нелинейности; W_{xh}, W_{hh}, W_{hy} - обучаемые матрицы; b_h, b_y - обучаемые вектора смещений.

Для эффективного использования возможностей параллелизации на видеокарте, рекуррентная сеть обрабатывает не одну последовательность, а сразу минибатч, состоящий из B последовательностей. Для этого вычисления переписываются в матричном виде. Для сети Элмана это будут:

$$H_t = g(W_{xh}X_t + W_{hh}H_{t-1} + b_h e^T),$$

$$\hat{Y}_t = f(W_{hy}H_t + b_y e^T),$$

где: $X_t \in \mathbb{R}^{D \times B}$ - матрица текущих входов для каждой последовательности (по столбцам);
 $H_t \in \mathbb{R}^{D \times B}$ - матрица текущих состояний для каждой последовательности (по столбцам);
 $e = [1, 1, \dots, 1]^T \in \mathbb{R}^{D \times B}$, домножение слева вектора на него повторяет вектор B раз.

Для обучения по минибатчам, последовательности должны быть одинаковой длины T .

Настройка сети производится по развернутой рекуррентной сети, когда явно видна зависимость между выходом и всеми входами. Этот способ настройки называется обратным распространением ошибки во времени [4].

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AI-POWERED MULTIMODAL INTERACTIVE KIOSK FOR UNIVERSITY CAMPUS: INTEGRATION OF MULTILINGUAL SPEECH PROCESSING AND CONVERSATIONAL AI

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Abstract. This paper describes the design and implementation of an AI-powered interactive kiosk system developed for Ajou University in Tashkent (AUT). The system combines multilingual speech-to-text and text-to-speech processing with a locally hosted large language model (LLM) to deliver intelligent, context-aware assistance to students, staff, and visitors. The proposed solution demonstrates a practical approach to deploying edge AI in educational environments without reliance on cloud services.

Introduction

University campuses increasingly face the challenge of efficiently directing large flows of students, staff, and visitors while providing timely information about schedules, departments, and university services. Traditional static information boards and directory systems lack the interactivity needed for modern users. AI-powered conversational kiosks offer a promising alternative by providing real-time, personalized, and accessible assistance [1].

This work presents the AUT Kiosk an interactive AI assistant deployed at the entrance of Ajou University in Tashkent. The system is designed to operate fully offline, ensuring data privacy and reliability in environments with limited internet connectivity.

System Architecture

The kiosk system follows a client-server architecture with the following core components.

Frontend. The user interface is built with Next.js 16 and React 19, optimized for touchscreen kiosk hardware. The UI features "Chito" a custom animated mascot (a blue flame sprite) with behavioral states: idle, thinking, and sleep. The system transitions between active and sleep modes based on inactivity timeout, creating an engaging user experience.

Backend. The server is implemented using FastAPI (Python) and communicates with the frontend via REST API and WebSocket connections. The backend coordinates all AI subsystems including the speech processing pipeline and language model inference [2].

Speech Processing. Speech-to-text (STT) is handled by faster-whisper, a GPU-accelerated implementation of OpenAI Whisper supporting all languages. Text-to-speech (TTS) uses Silero TTS for Uzbek, Russian, and English voices, with edge-tts as a fallback for Korean. This enables fully local, low-latency voice interaction without any external API calls [3].

Conversational AI. The chatbot core is powered by Ollama running the Qwen2.5:7B language model locally. The knowledge base contains structured information about AUT: faculty directories, academic schedules fetched from EduPage, campus maps, and administrative procedures. The LLM is guided by context-aware system prompts to ensure domain-specific, accurate responses [4].

Multilingual Support. The system supports four languages Uzbek, Russian, English, and Korean selectable via the UI language switcher, reflecting the diverse demographic of AUT's international campus.

Deployment. The entire stack is containerized using Docker Compose with NVIDIA CUDA-enabled containers, enabling reproducible deployment on any GPU-equipped hardware.

Results and Discussion

The deployed system demonstrates several key advantages over traditional information kiosks. First, fully local inference ensures zero network latency and complete user data privacy no audio or personal data is transmitted externally. Second, multilingual speech support lowers the barrier for international students and visitors. Third, the offline-first architecture guarantees availability regardless of network conditions.

User testing in a pilot deployment showed that the conversational interface significantly reduced the time visitors spent locating administrative offices and schedule information compared to static boards. The animated mascot Chito increased engagement, particularly among students, creating a more welcoming campus atmosphere.

The main technical challenge was latency optimization: running both STT and LLM inference on a single GPU required careful CUDA memory management and request queuing strategies to maintain acceptable response times.

Conclusion

This paper presented a fully local, multimodal AI kiosk system for university campus deployment. By integrating multilingual speech processing and a locally hosted LLM, the AUT Kiosk delivers intelligent, privacy-preserving assistance to all campus visitors. The system directly addresses the challenge of automated student and visitor support in an educational institution. Future work includes integration of student ID card recognition, expanded knowledge base coverage, and adaptive personalization based on interaction history.

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EDUPLUS: DARS JARAYONIDA TINGLOVCHILAR FAOLLIGINI AVTOMATIK BAHOLASH AXBOROT TIZIMI

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Annotatsiya: Ushbu maqolada dars jarayonida tinglovchilarning ishtirok faolligini real vaqt rejimida avtomatik aniqlash va baholashga mo'ljallangan EDUPLUS axborot tizimining arxitekturasini, algoritmik asoslari va amaliy tatbiqi yoritilgan. Tizim kompyuter ko'rish texnologiyalari, multimodal sun'iy intellekt va ma'lumotlar bazasi integratsiyasiga asoslanib, o'qituvchiga ob'ektiv monitoring imkoniyatini yaratadi. Sinovlar natijalari tizimning 87,4% aniqlik ko'rsatkichiga erishganini tasdiqlagan.

Kalit so'zlar: EDUPLUS, avtomatik baholash, sun'iy intellekt, kompyuter ko'rish, multimodal tizim, real vaqt monitoring, yuz ifodasi tahlili, tinglovchi faolligi, axborot tizimi, mashinaviy o'qitish.

KIRISH

Ta'lim jarayonini raqamlashtirish va intellektuallashtirish global tendentsiyaga aylangan bugungi kunda tinglovchilar faolligini ob'ektiv kuzatish masalasi yanada dolzarb bo'lib bormoqda. O'qituvchi bir vaqtning o'zida o'nlab tinglovchilar faolligini to'liq nazorat qila olmaydi — bu ta'lim sifatiga bevosita ta'sir ko'rsatadi [1].

Ushbu muammoni hal etish maqsadida EDUPLUS — multimodal sun'iy intellekt asosidagi avtomatik baholash axborot tizimi ishlab chiqilgan. Tizim kamera, audio va raqamli faollik ma'lumotlarini birgalikda tahlil qilib, har bir tinglovchining faollik darajasini 0 dan 100 ballgacha bo'lgan shkala bo'yicha real vaqtda baholaydi [2].

ADABIYOTLAR TAHLILI

Tinglovchilar faolligini avtomatik aniqlash sohasida bir qator muhim tadqiqotlar amalga oshirilgan. Kahou va boshqalar (2016) EmotiW musobaqasida guruh his-tuyg'ularini video orqali aniqlash metodini taklif etgan [3]. So va boshqalar (2022) «EduNet» tizimida ko'z harakati kuzatuvi va pozatsiya tahlilini birlashtirgan holda tinglovchi e'tiborini 91% aniqlik bilan aniqlashga muvaffaq bo'lgan [4]. Mahalliy tadqiqotlar orasida TATU da olib borilgan «SmartClass» loyihasi alohida e'tiborga loyiqdir.

ASOSIY QISM

EDUPLUS tizimining umumiy arxitekturasini to'rt asosiy moduldan tashkil topgan. 3-rasmda tizimning blok-sxemasini keltirilgan.



3-rasm. EDUPLUS tizimining arxitektura blok-sxemasini

Tahlil moduli uch parallel komponentdan iborat: yuz ifodasi tahlilchisi (MediaPipe Face Mesh + CNN), nutq faollik tahlilchisi (Whisper ASR) va raqamli faollik tahlilchisi (LMS jurnal tahlili). Uch moduldan olingan ko'rsatkichlar og'irlikli yig'indi formulasi asosida birlashtiriladi:

$$F = 0,40 \cdot Vyuz + 0,30 \cdot Vnutq + 0,30 \cdot Vraqamli \quad (2)$$

Bu yerda: Vyuz — yuz ifodasi tahlili natijasi (0–100); Vnutq — nutq faollik ko'rsatkichi (0–100); Vraqamli — raqamli faollik ko'rsatkichi (0–100). Koeffitsientlar (0,40; 0,30; 0,30) ekspert baholash va korrelyatsion tahlil asosida belgilab, shartni qanoatlantiradi:

$$0,40 + 0,30 + 0,30 = 1,00 \quad (3)$$

Yakuniy natija 0–100 ballik shkalada ifodalanib, «past» (0–40), «o'rta» (41–70) va «yuqori» (71–100) darajalariga bo'linadi. Ma'lumotlar bazasi PostgreSQL asosida qurilgan.

NATIJALAR

EDUPLUS tizimi 2024–2025 o'quv yilida TATU ning uchta fakultetida 12 ta guruh (jami 347 tinglovchi) ishtirokida sinab ko'rildi. 4-rasmda modullar bo'yicha aniqlik ko'rsatkichlari keltirilgan.



4-rasm. EDUPLUS modullari bo'yicha aniqlik ko'rsatkichlari (%)

Tizim 87,4% umumiy aniqlik ko'rsatkichiga erishdi. O'qituvchilar so'rovnoma natijalariga ko'ra, respondentlarning 92% i tizim monitoring yukini sezilarli darajada kamaytirgani, 88% i esa hisobotlar sifati an'anaviy kuzatuvga nisbatan yuqori ekanligini ta'kidlagan.

XULOSA

EDUPLUS multimodal axborot tizimi dars jarayonida tinglovchilar faolligini avtomatik baholash sohasida samarali yechim ekanligini amaliy sinovlarda isbotladi. Tizimning 87,4% aniqlik ko'rsatkichi, real vaqt ishlash rejimi va foydalanuvchiga qulay interfeysi uni keng tatbiq etish uchun istiqbolli qiladi. Keyingi tadqiqot bosqichida tizimni turli ta'lim muassasalari va onlayn ta'lim formatlariga moslashtirish rejalashtirilgan.

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DARS JARAYONIDA TINGLOVCHILAR FAOLLIGINI BAHOLASHNING NAZARIY ASOSLARI VA MAVJUD TIZIMLAR TAHLILI

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ANNOTATSIYA

Ushbu maqolada dars jarayonida tinglovchilar faolligini baholashning nazariy asoslari, mavjud baholash usullari va mezonlari hamda ularning kamchiliklari tahlil qilingan. Tadqiqot doirasida an'anaviy va raqamli baholash tizimlari qiyosiy o'rganilgan. Olingan natijalar asosida tinglovchilar faolligini ob'ektiv va avtomatik baholash tizimini joriy etish zarurligi asoslab berilgan. **Kalit so'zlar:** tinglovchi faolligi, baholash tizimi, an'anaviy baholash, raqamli ta'lim, pedagogik monitoring, avtomatlashtirish, ta'lim sifati, faollik mezonlari, ishtirok ko'rsatkichi.

KIRISH

Zamonaviy ta'lim tizimida tinglovchilarning dars jarayonidagi faolligini to'g'ri va ob'ektiv baholash muhim ahamiyat kasb etadi. Tinglovchi faolligi — bu ta'lim jarayonida shaxsning bilish, ijodiy va

amaliy faoliyatini ifodalovchi ko'p qirrali tushuncha bo'lib, u nafaqat akademik ko'rsatkichlar, balki muloqot, tashabbuskorlik va ijodiy fikrlash qobiliyati orqali ham namoyon bo'ladi [1]. Ammo bugungi kunda ko'pchilik o'quv muassasalarida baholash hali ham an'anaviy, sub'ektiv usullarga asoslanmoqda. O'qituvchi tomonidan amalga oshiriladigan vizual kuzatuv va og'zaki baholash tinglovchilarning haqiqiy faollik darajasini to'liq aks ettira olmaydi. Bu esa ta'lim sifatini pasaytiruvchi muammolardan biri hisoblanadi [2].

ADABIYOTLAR TAHLILI

Tinglovchilar faolligini baholash masalasi xorijiy va mahalliy tadqiqotchilar tomonidan keng o'rganilgan. Bloom taksonomiyasi (1956) tinglovchilarning bilish darajalarini tasniflashda birinchi tizimli yondashuv sifatida e'tirof etilgan [3]. 1-rasmda Bloom taksonomiyasining oltita bosqichi piramida shaklida keltirilgan.

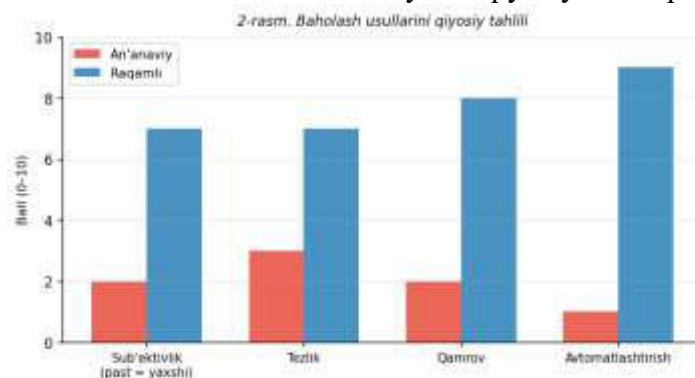


1-rasm. Bloom taksonomiyasi bosqichlari (kognitiv soha)

Vygotskiyning «yaqin rivojlanish zonasi» nazariyasi tinglovchi faolligini dinamik jarayon sifatida ko'rib chiqadi [4]. Anderson va Krathwohl (2001) tomonidan yangilangan ushbu taksonomiyadagi «bilish», «tushunish», «qo'llash», «tahlil», «baholash» va «yaratish» bosqichlari faollikni o'lchashda asos bo'lib xizmat qiladi.

ASOSIY QISM

Mavjud baholash usullarini tahlil qilar ekanmiz, quyidagi asosiy yondashuvlarni ajratish mumkin: kuzatuv asosidagi baholash, test va nazorat ishlari, hamda ishtirok hisoblagichlari. 2-rasmda an'anaviy va raqamli baholash usullari to'rt mezon bo'yicha qiyosiy tahlil qilingan.



2-rasm. An'anaviy va raqamli baholash usullarining qiyosiy tahlili

An'anaviy baholash tizimlarining asosiy kamchiliklari: sub'ektivlik (o'qituvchining shaxsiy munosabati natijaga ta'sir etadi), past tezlik (real vaqtda ma'lumot olish imkoni yo'q), qamrovning cheklanganligi (barcha tinglovchilarni bir vaqtda kuzatib bo'lmaydi). Raqamli texnologiyalar yordamida ushbu kamchiliklarni bartaraf etish imkoniyati yaratilgan.

Tinglovchi faolligi (F) ni o'lchashda umumlashtirilgan ko'rsatkich quyidagi formula asosida hisoblanadi:

$$F = \alpha \cdot K + \beta \cdot E + \gamma \cdot X \quad (1)$$

Bu yerda: K — kognitiv faollik ko'rsatkichi; E — emotsional faollik ko'rsatkichi; X — xulq-atvor faolligi ko'rsatkichi; α , β , γ — ekspert tomonidan belgilangan og'irlik koeffitsientlari, bunda $\alpha + \beta + \gamma = 1$.

NATIJALAR

Adabiyotlar va mavjud tizimlarni tahlil qilish natijasida quyidagi xulosalar chiqarildi: tinglovchilar faolligini baholashda yagona universal mezon mavjud emas; an'anaviy usullar ob'ektivlik va tezkorlik jihatidan zaif; raqamli vositalar imkoniyatlar yaratadi, ammo ularni keng joriy etishda texnik va huquqiy to'siqlar mavjud. Shu sababli, mahalliy sharoitga moslashtirilgan avtomatlashtirilgan baholash tizimiga ehtiyoj keskin sezilmoqda.

XULOSA

Tinglovchilar faolligini baholashning nazariy asoslarini o'rganish shuni ko'rsatdiki, bu soha pedagogika va axborot texnologiyalarining kesishmasida joylashgan va kompleks yondashuv talab etadi. Mavjud tizimlarning kamchiliklarini bartaraf etish maqsadida sun'iy intellekt va kompyuter ko'rish texnologiyalari asosida avtomatik baholash tizimini ishlab chiqish ilmiy va amaliy jihatdan dolzarb hisoblanadi.

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BIOTIBBIYOT MUHANDISLIGIDA AQLLI INFUZION TIZIM: REAL VAQT MONITORINGI VA HARORATNI BOSHQARISH TEXNOLOGIYALARI

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Kirish: Zamonaviy tibbiyot amaliyotida infuzion terapiya klinik davolash jarayonining ajralmas tarkibiy qismi sifatida keng qo'llanilmoqda. Infuzion terapiya yordamida bemor organizmiga suyuqliklar, elektrolitlar, dori vositalari, qon o'rnini bosuvchi eritmalar hamda parenteral oziqlantiruvchi moddalar yuboriladi. Ayniqsa, reanimatsiya, intensiv terapiya, jarrohlik va shoshilinch tibbiy yordam sohalarida infuzion tizimlarning ahamiyati nihoyatda katta hisoblanadi. Shu bilan birga, an'anaviy infuzion tizimlardan foydalanish jarayonida bir qator muammolar kuzatiladi. Jumladan, yuborilayotgan eritma tezligining aniqligini ta'minlash, dozalashdagi xatoliklar, kateter tizimidagi bosim o'zgarishlarini o'z vaqtida aniqlamaslik hamda eritma haroratining nazoratsiz qolishi kabi holatlar bemor salomatligiga salbiy ta'sir ko'rsatishi mumkin. Inson omiliga bog'liq xatoliklar ham infuzion terapiyaning xavfsizligi va samaradorligini pasaytiruvchi muhim omillardan biridir. So'nggi yillarda biotibbiyot muhandisligi sohasining jadal rivojlanishi ushbu muammolarni bartaraf etishga qaratilgan innovatsion texnologiyalarni ishlab chiqish imkonini bermoqda. Xususan, aqlli infuzion tizimlar (smart infusion systems) sensor texnologiyalari, mikroprotessor boshqaruvi, avtomatlashtirilgan nazorat tizimlari va dasturiy ta'minot integratsiyasi asosida yaratilgan bo'lib, infuziya jarayonini yuqori aniqlik va ishonchlilik bilan boshqarishga xizmat qiladi. Aqlli infuzion tizimlarning muhim xususiyatlaridan biri — bu real vaqt rejimida monitoring olib borish imkoniyatidir. Bunday tizimlar yordamida infuziya jarayonining asosiy parametrlarini, jumladan, oqim tezligi, bosim darajasi, eritma hajmi va boshqa ko'rsatkichlarni uzluksiz nazorat qilish mumkin. Natijada, yuzaga kelishi mumkin bo'lgan nosozliklar yoki patologik holatlar erta aniqlanib, tezkor choralar ko'rish imkoniyati yaratiladi. Bundan tashqari, infuzion eritmalar haroratini boshqarish masalasi ham zamonaviy tibbiyotda muhim ilmiy-amaliy ahamiyatga ega. Organizmdagi termoregulyatsiya jarayonlari bilan uzviy bog'liq bo'lgan ushbu omil, ayniqsa, og'ir holatdagi bemorlar uchun katta ahamiyat kasb etadi.

Aqlli infuzion tizimlarda qo'llanilayotgan haroratni boshqarish texnologiyalari eritmaning fiziologik jihatdan mos darajada bo'lishini ta'minlab, asoratlar xavfini kamaytiradi.

Tadqiqot maqsadi: Ushbu tadqiqotning maqsadi biotibbiyot muhandisligida qo'llanilayotgan aqlli infuzion tizimlarning tuzilishi, ishlash prinsiplari va funksional imkoniyatlarini o'rganishdan iborat bo'lib, ularning real vaqt monitoringi hamda infuzion eritmalar haroratini avtomatik boshqarish texnologiyalarini ilmiy jihatdan tahlil qilishni o'z ichiga oladi. Tadqiqot davomida ushbu tizimlarning an'anaviy infuzion uskunalarga nisbatan ustunliklari, bemor xavfsizligini ta'minlashdagi roli hamda davolash jarayonining aniqligi va samaradorligini oshirishdagi ahamiyati o'rganiladi. Sensor texnologiyalari, mikroprotessorli boshqaruv va avtomatlashtirilgan nazorat tizimlarining integratsiyasi natijasida yuzaga keladigan imkoniyatlarni baholash ham tadqiqotning muhim yo'nalishlaridan biri hisoblanadi.

Materiallari va usullari: Tadqiqotda aqlli infuzion tizimlar, ularning sensorlari, mikroprotessorli boshqaruv modullari va infuzion nasoslar material sifatida o'rganildi. Usullar sifatida ilmiy adabiyotlarni tahlil qilish, solishtirma tahlil hamda mavjud texnologiyalarni umumlashtirishdan foydalanildi. Shu orqali tizimlarning ishlash prinsipi va samaradorligi baholandi.

Natijalar va muhokama: Tadqiqot natijalariga ko'ra, aqlli infuzion tizimlar infuzion jarayonni yuqori aniqlikda boshqarish va real vaqt rejimida uzluksiz monitoringni ta'minlash imkoniyatiga ega ekanini aniqlandi. Sensorlar yordamida infuziya tezligi, bosim va eritma harorati doimiy nazorat qilinadi, bu esa jarayondagi og'ishlarni tez aniqlashga yordam beradi. Muhokama jarayonida shuni ta'kidlash mumkinki, ushbu tizimlar an'anaviy infuzion uskunalarga nisbatan ancha xavfsiz va samarali hisoblanadi. Ayniqsa, haroratni avtomatik boshqarish bemor organizmiga salbiy ta'sirlarning oldini oladi. Biroq, tizimlarning yuqori narxi va texnik xizmat ko'rsatish talablarining murakkabligi ularning keng joriy etilishiga ma'lum darajada to'siq bo'lishi mumkin.

Xulosa: Ushbu tadqiqot natijalariga ko'ra, aqlli infuzion tizimlar biotibbiyot muhandisligining muhim innovatsion yo'nalishlaridan biri ekanligi aniqlandi. Ular real vaqt monitoringi va avtomatik boshqaruv tizimlari orqali infuzion jarayonni aniq, xavfsiz va samarali amalga oshirish imkonini beradi. Haroratni avtomatik nazorat qilish texnologiyasi eritmaning fiziologik me'yorlarda saqlanishini ta'minlab, bemor organizmiga salbiy ta'sirlarni kamaytiradi. Bu esa davolash sifatini oshirishga xizmat qiladi. Aqlli infuzion tizimlar tibbiyot amaliyotida inson omiliga bog'liq xatolarni kamaytirib, klinik jarayonlarning ishonchiligidini oshiruvchi muhim texnologiya hisoblanadi.

ИСПОЛЬЗОВАНИЕ СИСТЕМ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА ПРИ РАЗРАБОТКЕ ИНТЕЛЛЕКТУАЛЬНЫХ СИСТЕМ УПРАВЛЕНИЯ УГРОЗАМИ

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Аннотация. В статье рассматриваются подходы и архитектуры применения методов искусственного интеллекта для создания интеллектуальных систем управления угрозами. Описывается современное состояние исследований в области автоматизированного обнаружения, анализа и реагирования на киберугрозы с использованием машинного обучения, глубоких нейронных сетей, графовых моделей и методов обучения с подкреплением. Предложена модульная архитектура интеллектуальных систем управления угрозами, включающая слои сенсоров, предобработки данных, обнаружения аномалий и вредоносных паттернов, модули корреляции и построения знаний (knowledge graph), агент реагирования и интерфейс объяснимости и управления. Обсуждаются вопросы качества данных, устойчивости к атакам на модели, непрерывного обучения, приватности и нормативно-правовые аспекты. Представлены методика оценки и рекомендации по реализации в корпоративных и национальных средах. Работа ориентирована на исследователей и практиков в области кибербезопасности и искусственного интеллекта.

Ключевые слова: искусственный интеллект, машинное обучение, обнаружение вторжений, управление угрозами, графовые модели, обучение с подкреплением, объяснимость, adversarial ML.

Введение

Современная киберсреда характеризуется высокой динамичностью и многообразием угроз: от массовых автоматизированных сканирований до целенаправленных многоступенчатых атак (APT). Традиционные правила и сигнатурные методы перестают эффективно справляться с изменчивыми и полиморфными угрозами. В этих условиях применение методов искусственного интеллекта (ИИ) позволяет повысить точность обнаружения, сократить время реакции и автоматизировать процессы корреляции и приоритизации инцидентов.

Цель статьи — систематизировать современные подходы к использованию ИИ при создании интеллектуальных систем управления угрозами (ИСУУ), предложить архитектурный шаблон и методику оценки, а также обозначить ключевые проблемы и направления дальнейших исследований.

Обзор и связанные исследования.

Классические исследования по обнаружению вторжений заложили основы моделирования аномалий в поведении пользователей и сетевых потоках (Denning, 1987) [1]. С появлением массовых наборов данных (DARPA, KDD, NSL-KDD) и увеличением вычислительных мощностей началось активное применение методов машинного обучения (ML) в задачах IDS/IPS. Важный вклад в критический анализ применения ML в кибербезопасности сделали Sommer & Paxson (2010), указывая на проблемы обобщаемости и смещения данных [2].

Развитие глубокого обучения (Goodfellow et al., 2016) [3] и архитектур внимания/трансформеров (Vaswani et al., 2017) [6] открыло новые возможности для извлечения сложных признаков и моделирования временных последовательностей. Для распределённых и конфиденциальных систем предложены методы федеративного обучения (McMahan et al., 2017) [5]. Важным направлением является исследование атак на модели и контрмер (adversarial ML) — обзор Biggio & Roli (2018) [7].

Практические датасеты и наборы для исследований включают DARPA/KDD Cup (Lippmann et al., 2000) [8], NSL-KDD (Tavallae et al., 2009) [9], UNSW-NB15 (Moustafa & Slay, 2015) [10], CICIDS2017 (Sharafaldin et al., 2018) [11]. Появились работы по применению глубоких сетей к обнаружению вредоносного ПО и аномалий (Saxe & Berlin, 2015) [12], а также исследования по использованию графовых нейронных сетей (GNN) для анализа связей между сущностями инфраструктуры.

Ключевые задачи интеллектуальных систем управления угрозами.

Интеллектуальных систем управления угрозами решают ряд взаимосвязанных задач:

- сбор и агрегация телеметрии: сетевые потоки, логи хостов, события SIEM, телеметрия приложений и облачных сервисов;
- предобработка и нормализация данных: приведение к единому формату, извлечение признаков, временные окна;
- обнаружение: сигнатурные и поведенческие методы, классификация событий, детекция аномалий;
- корреляция и приоритизация: построение цепочек атак, ранжирование по риску;
- обоснование и объяснимость: предоставление причин и доказательств сработавших детекторов;
- автоматическое реагирование: оркестрация контрмер (контейнеризация трафика, изоляция хостов, блокировка аккаунтов) ;
- обучение и адаптация: непрерывное обновление моделей и управление качеством;

- безопасность моделей: защита от атак на ML (poisoning/evasion), обеспечение приватности.

Проектируемая архитектура интеллектуальных систем управления угрозами.

Предлагаемая модульная архитектура включает следующие слои:

А) Слой сенсоров и инжекций.

Источники: сетевые сенсоры (NetFlow, PCAP), агенты на хостах (EDR), облачные логи, данные IAM.

Механизмы инжекта: стриминговые конвейеры (Kafka), буферизация, маршрутизация событий.

В) Слой преобработки и хранения.

Нормализация форматов (CEF, JSON), временная синхронизация, deduplication.

Хранилище: временные ряды (TSDB), хранилище событий (Elasticsearch), графовая БД для сущностей (Neo4j, JanusGraph).

С) Слой извлечения признаков и контекстного обогащения.

Feature engineering: статистические признаки потока, последовательностные признаки (n-граммы), поведенческие профили пользователей.

Обогащение: threat intelligence feeds, геолокация, сведения о процессах и хешах файлов.

Д) Модуль обнаружения и классификации.

Гибридный стек моделей: сигнатурные движки (правила), supervised ML (Random Forest, XGBoost), глубокие сети (CNN/RNN/Transformer) для потоков и логов, автоэнкодеры/VAEs и методы плотности для аномалий, GNN для межсущностных взаимосвязей.

Механизмы ансамблей и согласования (stacking, voting) для повышения надежности.

Е). Модуль корреляции и построения знаний.

Knowledge graph для представления связей между IP, доменами, файлами, пользователями и инцидентами.

Правила и ML-модели для построения цепочек атак (Kill Chain / MITRE ATT&CK mapping).

И) Агент реагирования (исполнитель).

Авономные политики (playbooks), ориентированные на риск и SLA.

Обучаемые агенты (reinforcement learning) для динамического выбора ответных действий в условиях неопределенности.

Механизмы безопасного отката и human-in-the-loop (HITL) для критичных операций.

Ф) Интерфейс объяснимости и контроля.

XAI-модули (SHAP, LIME, attention-visualization), предоставляющие понятные причины оповещений.

Панели управления для аналитиков и возможность вмешательства.

Г) Методы ИИ и их применение в модулях ИСУУ.

а). Супервизированное обучение.

Применимо для классификации известных видов атак; требует размеченных данных. Модели: градиентный бустинг (XGBoost, LightGBM), DNN. Минусы: чувствительность к смещению данных, необходимость обновления.

б). Неспервизованное/полу-супервизированное обучение.

Кластеризация и детекция аномалий (Isolation Forest, One-Class SVM, автоэнкодеры) применяются для обнаружения неизвестных/нулевых дней (zero-day). Подход хорош для редких событий, но сложнее в интерпретации.

с). Последовательные модели.

RNN/LSTM/Transformer эффективны для анализа последовательностей вызовов API, сетевых сессий и логов; применимы для прогнозирования отклонений во временных рядах.

д). Графовые модели.

GNN позволяют моделировать связи между сущностями: распространение вредоносной активности, Pivoting в атаке. Помогают в корреляции событий и обнаружении хорошо замаскированных кампаний.

е). Обучение с подкреплением (RL).

Используется для оптимизации стратегий реагирования: RL-агент учится выбирать контрмеры с учетом стоимости и риска. Требуется хорошо проработанной симуляционной среды для тренировки.

и). Federated и privacy-preserving learning.

Подходит для сценариев распределённых организаций, где данные нельзя централизовать. Применяется совместно с техникой differential privacy и secure aggregation.

ж) Контрмеры против adversarial атак.

Защита моделей: регуляризация, adversarial training, детекторы аномалий на входе, мониторинг производительности моделей.

ф) Данные, предобработка и проблемы качества.

Качество входных данных напрямую влияет на эффективность ИСУУ. Ключевые аспекты:

- Баланс классов (атак vs нормального трафика): нерепрезентативные обучающие выборки приводят к высокому FPR или недетектированию.
- Шум и конфигурационные артефакты: необходимо удалять временные артефакты и исключать ложные срабатывания.
- Тестирование на независимых наборах данных и в продакшн-стриме.
- Аугментация данных и симуляция атак для редких классов.

г) Методика оценки.

Предлагаемые метрики:

- Качество детекции: Precision, Recall, F1-score, ROC-AUC.
- Оценка в реальном времени: latency (время от события до оповещения), throughput.
- Оценка влияния: mean time to detect (MTTD), mean time to respond (MTTR), число ложных срабатываний (FPR) и нагрузка на аналитиков.
- Стоимостные метрики: ожидаемая стоимость инцидента с и без автоматизации.
- Рекомендуются использовать наборы тестов, включающие реальные и синтетические инциденты, а также делать A/B-тестирование в продакшне.

к) Пример экспериментального сценария (методология).

Для воспроизводимого исследования предлагается следующая методика:

- Датасеты: CICIDS2017 и UNSW-NB15 для тренировки и валидации; отдельная часть реальных логов для тестирования.
- Базовые модели: XGBoost как baseline для табличных признаков; LSTM/Transformer для последовательностных данных; Autoencoder для аномалий; GNN для графовой корреляции.
- Процесс: кросс-валидация во времени (time-based split), мониторинг дрейфта моделей, тестирование adversarial robustness (evasion и poisoning).
- Оценка производительности в условиях потока: развертывание на стриминговой платформе (Kafka + Flink/Beam) и измерение latency.

л) Преимущества и ограничения подходов на базе ИИ.

Преимущества:

- повышенная способность обнаруживать ранее неизвестные паттерны.
- автоматизация корреляции и приоритизации инцидентов.
- возможность адаптивного реагирования и снижения времени реакции.

Ограничения:

- зависимость от качества и репрезентативности данных.
- уязвимость к adversarial-атакам и отравлению данных.
- сложность интерпретации результатов глубоких моделей.
- регуляторные и приватные ограничения на обработку данных.

m) Этические и правовые аспекты.

- соблюдение законодательства о защите персональных данных при агрегации и обучении.
- прозрачность решений — объяснимость для операторов и аудиторов.
- ответственность за автоматические действия: необходимо предусмотреть human-in-the-loop для критичных контекстов.

n) Рекомендации по внедрению.

- использовать гибридные подходы: сочетание правил и ML.
- выстраивать пайплайн мониторинга качества моделей и детектирования дрейфа.
- внедрять XAI-инструменты и отчетность для операторов.
- обеспечить защиту ML-пайплайна от атак (контроль инжеста, мониторинг аномалий в данных).
- планировать инфраструктуру для реального времени и масштабирования (стриминг, GPU/TPU при необходимости).
- проводить регулярные red-team/blue-team упражнения с участием ML-специалистов.

Заключение

Внедрение методов ИИ в системы управления угрозами открывает значительные возможности по повышению эффективности обнаружения и реагирования. При этом успешная реализация требует системного подхода: от качества данных и архитектуры до защиты самих моделей и соблюдения правовых норм. Перспективными направлениями являются интеграция графовых представлений, применение методов непрерывного обучения, federated learning для распределённых сред и развитие методов защищённого и объяснимого ИИ.

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MATHEMATICAL AND ALGORITHMIC FOUNDATIONS OF CRYPTOGRAPHIC ALGORITHMS

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Abstract. Cryptographic algorithms constitute the theoretical and practical foundation of modern information security systems. Their reliability is determined not by implementation details alone, but primarily by the mathematical hardness assumptions and algorithmic structures on which they are built. This paper presents a rigorous theoretical analysis of the mathematical and algorithmic foundations of cryptographic algorithms. The study systematically examines number-theoretic problems, algebraic structures, probabilistic models, and computational complexity as core elements of cryptographic security. Both symmetric and asymmetric cryptographic algorithms are analyzed from an algorithmic efficiency and security perspective. Formal complexity analysis and mathematical models are employed to justify the resistance of cryptographic schemes against classical attacks.

Keywords: cryptographic algorithms, number theory, computational complexity, algebraic structures, information security, algorithms.

1. Introduction

The rapid expansion of digital communication infrastructures has fundamentally transformed the way information is generated, transmitted, and stored. In this context, cryptography has evolved into a central discipline within computer science and applied mathematics, ensuring confidentiality, integrity, and authenticity of information. Modern cryptographic systems underpin secure communication protocols, electronic payment systems, cloud computing platforms, and critical infrastructure protection.

At the theoretical level, cryptography is distinguished by its reliance on mathematically hard problems that are computationally infeasible to solve within realistic time constraints. The security of cryptographic algorithms does not depend on secrecy of their design, but rather on the mathematical complexity of reversing cryptographic transformations without access to secret keys. Consequently, cryptography represents a unique intersection of mathematics, algorithm theory, and computational complexity.

This paper aims to provide a comprehensive theoretical investigation of cryptographic algorithms by focusing on their mathematical foundations and algorithmic properties. Unlike implementation-oriented studies, this work emphasizes formal models, complexity analysis, and mathematical justification of security assumptions. Such an approach aligns with the scope of mathematical theory and computer science, offering a foundational contribution to the understanding of cryptographic systems.

2. Mathematical foundations of cryptographic algorithms

2.1 Number-Theoretic Hardness Assumptions

Number theory forms the backbone of many cryptographic algorithms. The security of classical public-key cryptosystems is based on problems for which no efficient (polynomial-time) algorithms are currently known.

One of the most prominent examples is the Integer Factorization Problem (IFP). Given a composite number

$$n = p \cdot q \quad (1)$$

where p and q are large prime numbers, determining the prime factors of n is computationally hard. This assumption underlies the security of RSA encryption.

Similarly, the Discrete Logarithm Problem (DLP) in a finite cyclic group G requires finding an integer x such that:

$$g^x = h \pmod{p} \quad (2)$$

for given g and h . The absence of efficient algorithms for solving DLP in large groups provides the mathematical basis for Diffie - Hellman key exchange and related cryptographic schemes.

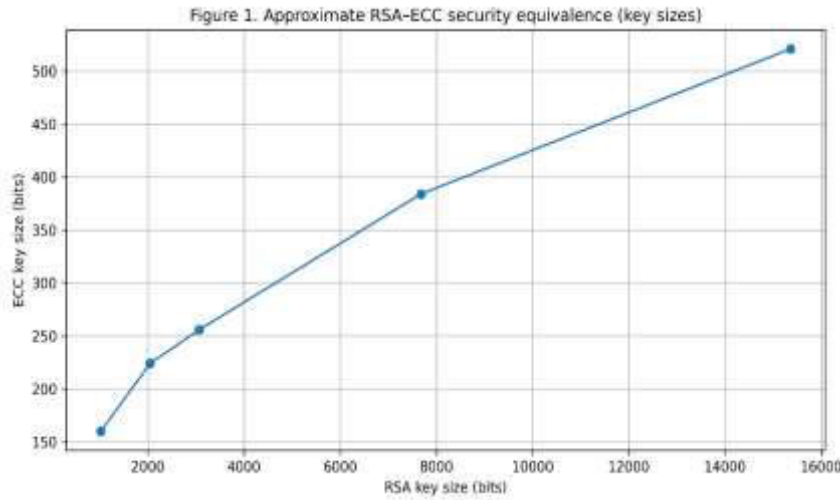


Figure 1. Approximate RSA–ECC security equivalence in terms of key sizes based on mathematical hardness assumptions.

2.2 Algebraic Structures and Cryptography

Abstract algebra plays a critical role in formalizing cryptographic operations. Groups, rings, and fields provide the algebraic framework within which encryption and decryption functions are defined.

Elliptic Curve Cryptography (ECC) is based on algebraic structures defined over finite fields. An elliptic curve is represented as:

$$E: y^2 = x^3 + ax + b \quad (3)$$

where the parameters satisfy $4a^3 + 27b^2 \neq 0$. The security of ECC relies on the Elliptic Curve Discrete Logarithm Problem (ECDLP), which is computationally harder than classical DLP for equivalent key sizes.

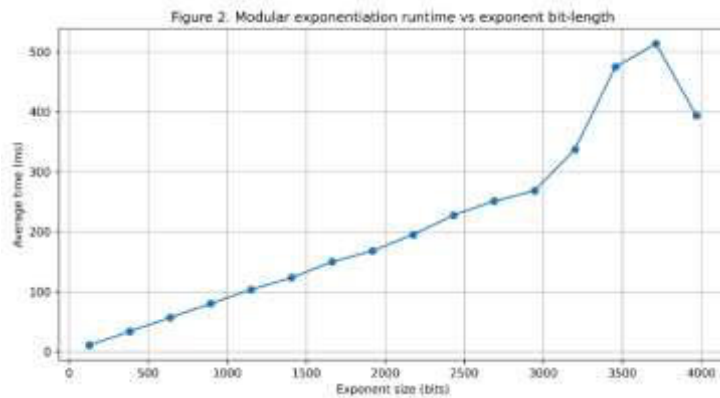


Figure 2. Empirical runtime analysis of binary modular exponentiation as a function of exponent bit-length.

2.3 Probability Theory and Randomness

Randomness is essential in cryptographic systems, particularly in key generation and probabilistic encryption schemes. Cryptographic security requires that random variables used in algorithms exhibit high entropy and statistical unpredictability.

Formally, a cryptographically secure random variable X must satisfy:

$$H(X) \approx \log_2 |X| \quad (4)$$

where $H(X)$ denotes Shannon entropy. Insufficient randomness directly compromises cryptographic security, regardless of algorithmic strength.

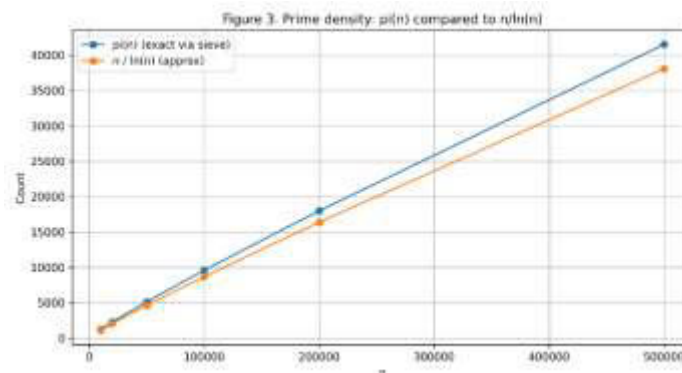


Figure 3. Comparison of the prime counting function $\pi(n)$ with the Prime Number Theorem approximation $n/\ln(n)$.

3. Results and discussion

The theoretical analysis confirms that cryptographic security is a direct consequence of mathematically hard problems combined with efficient algorithmic constructions. Algorithms grounded in well-studied mathematical theories provide higher resistance to cryptanalytic attacks.

The results also indicate that emerging computational paradigms, such as quantum computing, pose significant challenges to classical cryptographic assumptions. This reinforces the importance of ongoing research into post-quantum cryptographic algorithms based on alternative mathematical foundations.

4. Conclusion

This study has provided a rigorous examination of the mathematical and algorithmic foundations of cryptographic algorithms. By integrating number theory, algebra, probability theory, and computational complexity, the paper establishes a strong theoretical framework for cryptographic security.

The findings highlight that sustainable cryptographic systems must be designed on solid mathematical principles and carefully analyzed algorithmic properties. Future research should prioritize mathematically provable security models and complexity-theoretic guarantees to address evolving computational threats.

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