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DEVELOPMENT OF AN INFORMATION SYSTEM ARCHITECTURE FOR HEALTHCARE INSTITUTIONS USING ARTIFICIAL INTELLIGENCE

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Abstract. This article presents the development and implementation results of a modern information model for a medical system integrating artificial intelligence (AI) technologies to enhance diagnostic accuracy and efficiency. One of the core challenges in designing and deploying such systems lies in the processing of medical imaging data (MRI, CT, X-ray) and ensuring compatibility with electronic medical records (EMRs). The paper outlines key methods and architectural solutions used in the model and highlights their role in delivering accurate, reliable, and AI-supported medical diagnostics. *Results.* An architecture was developed and tested, comprising imaging modules, cloud platforms, medical data repositories, and AI algorithms. The system enables automated image analysis and seamless integration with EMRs. Experimental validation confirmed a significant improvement in diagnostic accuracy and reduced data processing time, while preserving the physician's central role in decision-making. The system meets international standards for data security and confidentiality. *Scientific Novelty.* A modular and scalable AI-driven diagnostic architecture is proposed, adaptable to various clinical contexts. Novel algorithms were developed to detect anomalies in medical images with high precision, alongside mechanisms for expert verification. The originality lies in the systemic integration of AI into medical workflows while maintaining clinician oversight and compliance with regulatory standards. *Practical Value.* The proposed model can be implemented in clinical settings to optimize diagnostic workflows and enhance healthcare quality. It reduces physician workload, accelerates diagnostic decisions, and improves access to high-accuracy diagnostics.

Key words: Artificial Intelligence (AI), medical imaging, diagnostic accuracy, healthcare systems, medical information model, image processing

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МЕДИЦИНАЛЫҚ МЕКЕМЕЛЕРГЕ АРНАЛҒАН ЖАСАНДЫ ИНТЕЛЛЕКТТІ ҚОЛДАНАТЫН АҚПАРАТТЫҚ ЖҮЙЕ АРХИТЕКТУРАСЫН ӘЗІРЛЕУ

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Аннотация. Мақалада диагностика дәлдігін және тиімділігін арттыру мақсатында жасанды интеллект (ЖИ) технологияларын интеграциялау арқылы медициналық жүйенің заманауи ақпараттық моделі ұсынылады. Мұндай жүйелерді жобалау мен енгізудегі негізгі міндеттердің бірі – медициналық кескіндерді (МРТ, КТ, рентген) өңдеу және оларды электронды медициналық жазбалармен үйлестіру. Бұл – диагноз қоюдың сенімділігіне, клиникалық шешімдердің тұрақтылығына және пациенттің қауіпсіздігіне тікелей әсер ететін аса маңызды үдеріс. Жұмыста модельді құруда қолданылған негізгі әдістер мен архитектуралық шешімдер сипатталып, олардың ЖИ көмегімен дәл әрі сенімді диагностика жүргізудегі рөлі негізделген. *Нәтижелер.* Кескіндеу модульдері, бұлттық платформалар, медициналық мәліметтер базалары және ЖИ алгоритмдері кіретін жүйенің архитектурасы әзірленіп, сынақтан өткізілді. Жүйе кескіндерді автоматты түрде өңдеуді және оларды электронды медициналық жазбалармен біріктіруді қамтамасыз етеді. Эксперимент нәтижелері диагноз қою дәлдігінің артқанын және деректерді өңдеу уақытының қысқарғанын көрсетті. Сонымен қатар, дәрігердің шешім қабылдаудағы рөлі сақталды және жүйе халықаралық қауіпсіздік пен құпиялық стандарттарына сай екені дәлелденді. *Ғылыми жаңалығы.* Клиникалық міндеттердің кең ауқымына бейімделе алатын модульдік және масштабталатын ЖИ-негізіндегі диагностикалық архитектура ұсынылды. Медициналық кескіндердегі аномалияларды жоғары дәлдікпен анықтай алатын жаңа алгоритмдер мен оларды дәрігер арқылы тексеру механизмдері жасалды. Жаңалық – ЖИ-ді медициналық үдерістерге жүйелі түрде интеграциялау тәсілінде, дәрігердің бақылауын сақтай отырып және нормативтік талаптарды ескеруде болып табылады. *Практикалық құндылық.* Ұсынылған модельді клиникалық тәжірибеге енгізу диагностикалық үдерістерді оңтайландырып, медициналық қызмет сапасын арттыруға мүмкіндік береді. Жүйе медициналық персоналдың жүктемесін азайтып, диагноз қоюды жеделдетеді және дәл диагностикаға қолжетімділікті кеңейтеді. Бұл модель ЖИ технологияларын қолдана отырып, денсаулық сақтау саласын цифрландырудың тиімді бағыты ретінде қарастырылады.

Түйін сөздер: жасанды интеллект (ЖИ), медициналық бейнелеу, диагностикалық дәлдік, денсаулық сақтау жүйесі, медициналық ақпараттық модель, кескінді өңдеу

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РАЗРАБОТКА АРХИТЕКТУРЫ ИНФОРМАЦИОННОЙ СИСТЕМЫ ДЛЯ МЕДИЦИНСКИХ УЧРЕЖДЕНИЙ С ИСПОЛЬЗОВАНИЕМ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА

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Аннотация. В статье представлены сведения и результаты разработки современной информационной модели медицинской системы с интеграцией технологий искусственного интеллекта (ИИ) для повышения точности и эффективности диагностики. Одной из ключевых задач при проектировании и внедрении подобных систем является обработка медицинских изображений (МРТ, КТ, рентген) и обеспечение совместимости с электронными медицинскими записями. В работе изложены основные методы и архитектурные решения, использованные при создании модели, а также обоснована их роль в обеспечении надёжной, точной и безопасной медицинской диагностики с поддержкой ИИ. *Результаты.* Разработана и протестирована архитектура системы, включающая модули визуализации, облачные платформы, базы медицинских данных и алгоритмы ИИ. Система обеспечивает автоматизированный анализ изображений и их интеграцию в электронные медицинские записи. Проведённый эксперимент подтвердил повышение точности диагностики и сокращение времени обработки данных при сохранении роли врача в принятии решений. Обеспечена совместимость с международными стандартами безопасности и конфиденциальности. *Научная новизна.* Предложена оригинальная модульная архитектура медицинской ИИ-системы с возможностью масштабирования под различные клинические задачи. Разработаны алгоритмы, способные выявлять аномалии на изображениях с высокой достоверностью, и механизмы их верификации врачом. Новизна заключается в системном подходе к интеграции ИИ в медицинские процессы с сохранением контроля со стороны специалиста и соблюдением нормативных требований. *Практическая ценность.* Результаты могут быть внедрены в клиниках для оптимизации диагностических процедур и повышения качества обслуживания. Система снижает нагрузку на медицинский персонал, ускоряет постановку диагноза и расширяет доступ к высокоточной диагностике.

Ключевые слова: искусственный интеллект (ИИ), медицинская визуализация, диагностическая точность, системы здравоохранения, модель медицинской информации, обработка изображений

Introduction. In recent decades, the use of artificial intelligence (AI) technologies in the field of medicine has significantly expanded, opening new horizons for the diagnosis and treatment of diseases. One of the most promising areas is the automated analysis of medical images, such as MRI, CT scans, and X-rays. AI and machine learning can substantially improve diagnostic accuracy by detecting even those anomalies that might be overlooked by the human eye. However, despite the progress in this field, a key challenge remains the integration of AI technologies into real clinical practice, where the role of the physician remains equally important (Ramyavarshini, et al., 2024). Modern medical information systems actively employ various technologies for processing, storing, and transmitting medical data, including PACS (Picture Archiving and Communication Systems) and EHR (Electronic Health Records). These systems provide physicians with comprehensive patient information, aiding in making informed decisions. The introduction of AI into this process significantly enhances diagnostic efficiency, but it is essential to understand that AI does not replace the physician; rather, it serves as a powerful tool to assist in their work (Arijita, et al., 2024).

This article is dedicated to the study of an information model for a system that integrates AI for medical image processing and interacts with medical records. We will explore the architecture of such a system, as well as the roles of doctors, patients, and AI models in the diagnostic and treatment processes (Vanessa, et al., 2024). The primary focus will be on the interaction between the system components, including medical devices, cloud technologies, databases, and AI models. It is important to emphasize that the role of the doctor remains critical at all stages: from initial diagnosis to decision-making based on AI analysis.

The goal of this article is to demonstrate how the integration of AI into medical practice can improve the accuracy and speed of diagnosis, as well as how different system components interact to ensure high-quality and safe patient care.

AI in medical systems. The application of artificial intelligence in medicine covers a wide range of tasks, from diagnosing diseases to personalized treatment. AI models trained on large volumes of data can process complex medical images and provide doctors with valuable diagnostic clues. For example, AI algorithms can be used to detect cancer at an early stage, significantly increasing the chances of successful treatment. AI algorithms, particularly in radiology and pathology, excel in analyzing medical images like X-rays, CT scans, and MRIs, achieving precision often surpassing human experts (Jiang, et al., 2017). AI accelerates drug discovery by identifying novel drug targets and automating processes, reducing the time and cost of development (Shaheen, 2021). AI analyses genetic, clinical, and lifestyle data to develop tailored treatment plans, optimizing therapeutic outcomes (Rich & Winston, 2024). Predictive models identify at-risk patients and forecast disease progression, aiding in early intervention and prevention strategies (Beronius, et al., 2022). Robotic systems powered by AI perform surgeries with exceptional precision, reducing errors and improving patient outcomes (Mukherjee, et al., 2023). AI-driven chatbots and virtual assistants provide real-time medical advice and support, enhancing patient engagement and reducing healthcare professionals' workload (Rich & Winston, 2024). Despite its potential, AI adoption faces challenges like data privacy concerns, algorithmic biases, and the need for interpretability and regulatory compliance (Beronius, et al., 2022). Authors in (Pallavi, et al., 2022) highlights the role of artificial intelligence (AI) in healthcare, particularly in clinical decision support and medical imaging analysis. AI aids physicians in making informed decisions and identifying critical details in

CT scans, X-rays, and MRIs, improving treatment outcomes. Its significance was especially evident during the COVID-19 pandemic, where it accelerated responses to medical challenges (Pallavi, et al., 2022). Artificial intelligence (AI) enhances computer systems to perform tasks akin to human cognition across various fields, significantly improving daily life. In healthcare, advancements in information and communications technology (ICT) have driven progress in electronic health (eHealth) and mobile health (mHealth). AI and deep machine learning utilize big data-comprehensive medical and disease-related information—to refine diagnosis and treatment. For instance, cardiovascular imaging now integrates big data and pathology for personalized therapies, while cancer care benefits from AI's insights into tumor biology and precision medicine. This paper reviews AI-driven eHealth and mHealth applications, highlighting their role in advancing diagnosis and patient car (Yang, et al., 2021). Artificial intelligence (AI) is revolutionizing healthcare with applications in diagnosis, robotic surgeries, and research. Powered by vast healthcare data and advanced analytics, AI mimics human expertise but with greater efficiency. For instance, surgical robots, though slower, deliver superior precision and uniformity compared to human surgeons, reducing failure rates. AI relies on algorithms, primarily in machine learning (ML) and natural language processing (NLP), which are essential for achieving healthcare goals. This study highlights current advancements, explores AI's potential, and encourages its integration into scientific research. Ongoing innovations will continue to broaden AI's impact and redefine its applications in healthcare (Quazi, et al., 2022). In the work (Shaheen, 2021), the role of artificial intelligence (AI) in healthcare is discussed, including its impact on accelerating drug discovery, optimizing clinical trials, and improving patient care. AI streamlines process, analyses large datasets, and provides insights to enhance quality of life. In the study (Sharma, et al., 2022) authors reviewed AI implementation in healthcare through empirical research. It found that most AI systems support decision-making rather than act autonomously.

In addition, AI can be integrated into healthcare information systems, such as electronic health records (EHR), to improve data storage and transmission, as well as automatic synchronization with test results and diagnostic images. In this way, AI not only improves diagnostics, but also increases the overall efficiency of the healthcare system. In a medical information system (MIS), the doctor plays a key role, ensuring the integration of medical data, diagnostic accuracy, decision making and control over the treatment process. Modern information technologies do not replace the physician, but rather enhance his or her capabilities, providing tools for more effective and personalized patient care. With the development of AI technologies, a new role for doctors is emerging as "tuner" and auditor of AI systems. The doctor must not only interpret results but also adjust AI algorithms when necessary to ensure data accuracy and relevance. This collaboration between the doctor and AI becomes a key element in modern healthcare systems.

Modern technologies in the field of medical diagnostics. In recent years, technology in the medical field has undergone significant changes, especially in the field of diagnosing diseases using medical images. The authors in (Chernobrivtseva & Misyurin, 2022) explored the use of machine learning and neural network technologies in modern medical imaging to improve the diagnosis of diseases such as cancer. These technologies enhance diagnostic accuracy, reduce errors, and shorten the time required for image analysis. The development of fields like radiomics and radio genomics is linked to the use of big data and artificial intelligence algorithms, supporting a personalized approach to treatment. In the future, these technologies could become valuable tools for doctors, providing a second opinion when selecting treatment options for patients (Chernobrivtseva & Misyurin, 2022). In (Matsuo, et al., 2024) the authors discuss the growing impact of Point-of-Care Diagnostics (POCDs) in medical mycology, particularly focusing on lateral flow assays (LFAs) for various fungal diseases. They also explore emerging diagnostic techniques like body fluid analysis, LAMP, CRISPR-based methods, and artificial intelligence. The study highlights how POCDs, such as Cryptococcus and Histoplasma antigen LFAs, have become mainstream diagnostics, offering benefits like rapid, accurate results, reduced patient discomfort, and cost savings. The authors emphasize the importance of integrated fluidics and microtechnology in advancing diagnostic capabilities in mycology (Matsuo, et al., 2024). In the mini review, the authors discuss advancements in diagnostic imaging technologies, emphasizing novel contrast agents developed with nanotechnology to enhance sensitivity, tissue specificity, and reduce systemic toxicity. Imaging methods like CT, MRI, and PET are crucial for disease detection but face limitations such as high costs, ionizing radiation exposure, and reliance on skilled radiologists. Future research aims to improve non-ionizing technologies like NMR and Ultrasound for personalized, cost-effective diagnostics, leveraging nanotechnology for targeted and accurate imaging ((Samy, 2019), (Casciaro, 2011)).

This Comparative Analysis of AI Systems in Ophthalmology. Table 1 compares AI systems in ophthalmology based on their features, strengths, and limitations. Each system is tailored to specific applications, with choices depending on institutional needs, available infrastructure, and intended use cases. Systems like *IDx-DR* and *Eyenuk* are best suited for broad clinical use, while platforms like *DeepMind* and *Heidelberg AI Tools* excel in specialized or research-focused applications.

Table 1 – Comparative Analysis of Existing AI Systems in Ophthalmology

System	Primary Focus	Key Features	Strengths	Limitations
IDx-DR	Diabetic Retinopathy Detection	FDA-approved, analyzes retinal images.	High accuracy: no specialist required for diagnosis.	Limited to diabetic retinopathy detection.
Eyenuk	Retinal Disease Detection	AI for diabetic retinopathy, macular edema, and AMD.	Comprehensive analysis of multiple retinal diseases.	Requires high-quality imaging data for accuracy.

DeepMind	General Ophthalmology Diagnostics	Analyzes OCT scans for glaucoma and macular degeneration.	Accurate for multiple conditions; widely validated.	Requires advanced imaging equipment.
Retina-AI Health	Screening and Referral Management	Focuses on triaging retinal diseases and providing referral recommendations.	Simplifies referral process for clinicians.	Limited scope beyond triage and referral.
Visulytix Pegasus	Multi-Disease Ophthalmic AI	Detects glaucoma, diabetic retinopathy, and AMD.	Multi-disease detection in a single platform.	Limited adoption in non-English-speaking regions.
ZEISS VISUHEALTH	Imaging and Diagnostics Integration	Combines imaging data with AI for precise diagnostics.	Seamless integration with ZEISS devices.	High implementation costs.
NVIDIA Clara AI	Retinal Image Segmentation and Analysis	Provides tools for building custom AI solutions for ophthalmology.	Customizable for specific institutional needs.	Requires technical expertise for customization.
Orbis Cybersight AI	Screening in Remote Areas	Cloud-based AI screening for underserved regions.	Enables accessibility in low-resource settings.	Dependent on internet connectivity.
Heidelberg AI Tools	Advanced Retinal Imaging Analysis	Focused on ultra-high-resolution imaging.	Excellent for research and precision diagnostics.	Expensive; not suited for general clinical use.

AI systems for ophthalmology, such as IDx-DR, Eyenuk, and EyeArt, have significant potential for implementation in Kazakhstan. However, successful adoption will require:

- Investments in diagnostic equipment and infrastructure.
- Adaptation of algorithms to local data and conditions.
- Development of national standards and provision of specialist training.

With the right approach, these systems can greatly enhance the accessibility and quality of ophthalmic care, particularly in remote and rural regions of the country. Considering the aforementioned factors, it is both practical and necessary to develop an information system specifically tailored to meet the needs of ophthalmological centers in Kazakhstan.

Methodology and materials. A system designed to work with medical images and diagnoses using AI includes several key components that interact with each other to process data, make decisions, and provide medical reports. It is important to note that these components can be hardware (medical equipment) and software (databases, AI models, user interfaces). Let's consider them in more detail in Table1:

Table 2 – Key Components of a Medical Image Recognition System

Component	Description	Role in the system
Medical Equipment	Devices for capturing images, such as X-ray machines, Ultrasound, CT, MRI.	Captures images and data that are later used for diagnosis.
Medical Database	A system for storing information about patients, medical images, and diagnoses.	Ensures storage, retrieval, and access to patient data and diagnoses.
AI Image Recognition Models	Machine learning models for analyzing medical images (e.g., neural networks).	Processes images and recognizes abnormalities or pathologies for diagnosis.
Image Processing (Image Processor)	Algorithms for pre-processing images, such as filtering and improving quality.	Prepares the image for further analysis by enhancing its quality.
Recognition Algorithms	AI models for analyzing and recognizing patterns in images (e.g., identifying diseases).	Detects diseases or conditions in images.
Report Generation System	Mechanism for generating reports based on diagnoses and image processing results.	Generates diagnostic reports that are provided to doctors for decision-making.
User Interface (UI)	Graphical interface through which doctors or medical personnel interact with the system.	Provides access to patient data, processed images, and diagnostic results.
Security System	Mechanisms for protecting data, such as encryption and authentication.	Protects personal patient data and medical records from unauthorized access.
Doctor	A medical specialist using the system for diagnosis and decision-making.	Interacts with the system to view reports, analyze diagnoses, and make treatment decisions.

The Table 1 provides an overview of the key components within a medical image recognition system, outlining their roles in the process of capturing, storing, and analyzing medical images. While it introduces essential elements like medical equipment, databases, AI models, and user interfaces, it does not delve into the specific features of these components. To provide a deeper understanding, the Table 2 expands on this by not only describing the role of each component but also highlighting their specific technical features, such as the capabilities of AI models, image processing algorithms, and cloud services. This transition from a high-level overview to a more detailed explanation helps illustrate how these components function together in a comprehensive system, with a focus on their practical implementation and technical characteristics.

Table 3 – Role and Features of Key Components in a Medical Image Recognition System

Component	Role	Features
Scanners (e.g., CT, MRI, X-ray, Ultrasound)	Captures high-quality medical images used for diagnosis and treatment.	Provide detailed images of internal organs and tissues; each type specialized for different parts of the body (e.g., MRI for soft tissues, X-ray for bones).
PACS (Picture Archiving and Communication System)	Stores, retrieves, and shares medical images within a healthcare network.	Supports image storage, management, and distribution; ensures easy access for radiologists and healthcare providers across locations.
Cloud Services	Stores and processes medical data remotely, offering scalability and flexibility.	Provides remote access, secure storage, and scalability for large datasets; enables real-time data processing and collaboration.
EHR (Electronic Health Records)	Stores comprehensive patient medical information, including images, diagnoses, and treatment history.	Centralized database for patient information; supports real-time updates; integrates with medical devices and third-party systems.

AI Models (e.g., Deep Learning for Image Recognition)	Analyzes medical images to detect abnormalities, diseases, or conditions (e.g., tumors, fractures).	Uses neural networks, convolutional layers (CNNs), and other machine learning techniques to automate image interpretation and improve diagnosis accuracy.
Image Processing Algorithms	Enhances image quality for better visualization and analysis.	Includes algorithms for noise reduction, contrast enhancement, edge detection, and segmentation.
Clinical Decision Support Systems (CDSS)	Provides doctors with AI-driven suggestions based on medical data and analysis.	Uses patient data and medical history to provide clinical recommendations, improving decision-making efficiency and accuracy.
Security Systems	Protects patient data and medical records from unauthorized access.	Includes encryption, user authentication, and secure communication protocols to ensure data privacy and comply with regulations like HIPAA.
User Interface (UI)	Allows healthcare providers to interact with the system, view reports, and analyse images.	Simple, intuitive interface for displaying images, reports, and patient data; often integrates with EHR and PACS systems.
Data Analytics and Reporting Tools	Analyses patient data to generate insights and reports for medical professionals.	Includes advanced data analysis tools and visualization techniques to support diagnosis, treatment plans, and medical research.

Development of IS architecture. The class diagram will describe the structure of the system, including classes for medical equipment, image processing, databases, AI models, and other components, and their relationships.

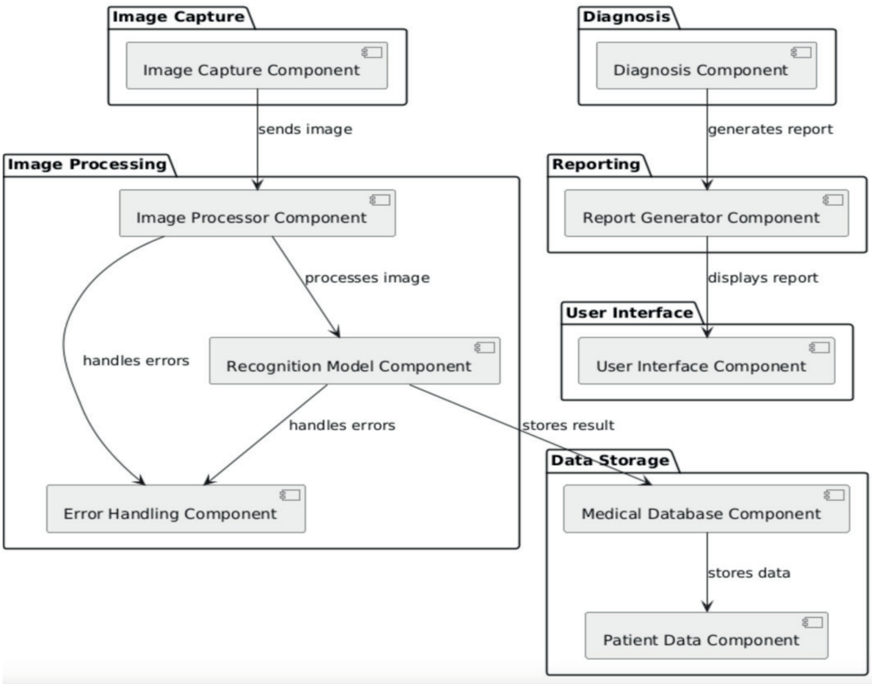

Fig.1 – General structure of the system

The component diagram shows how the different parts of the system interact with each other, including scanners, imaging systems, databases, AI models, and APIs.

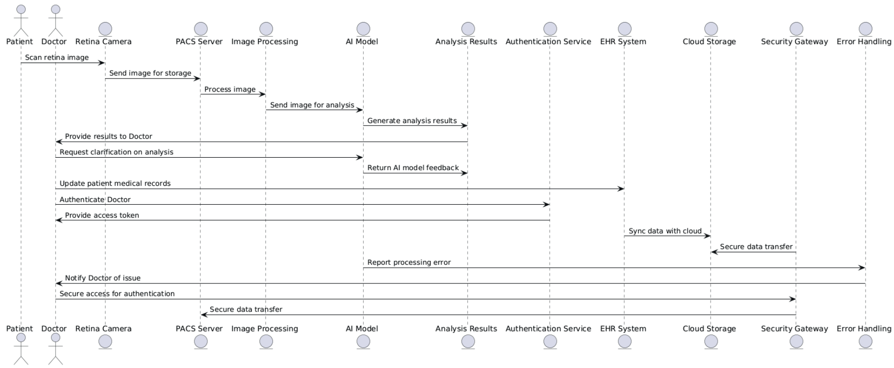

Fig.2 – Sequence diagram of the system

A sequence diagram describes how components interact to perform a task, such as scanning, image processing, recognition, and report generation.

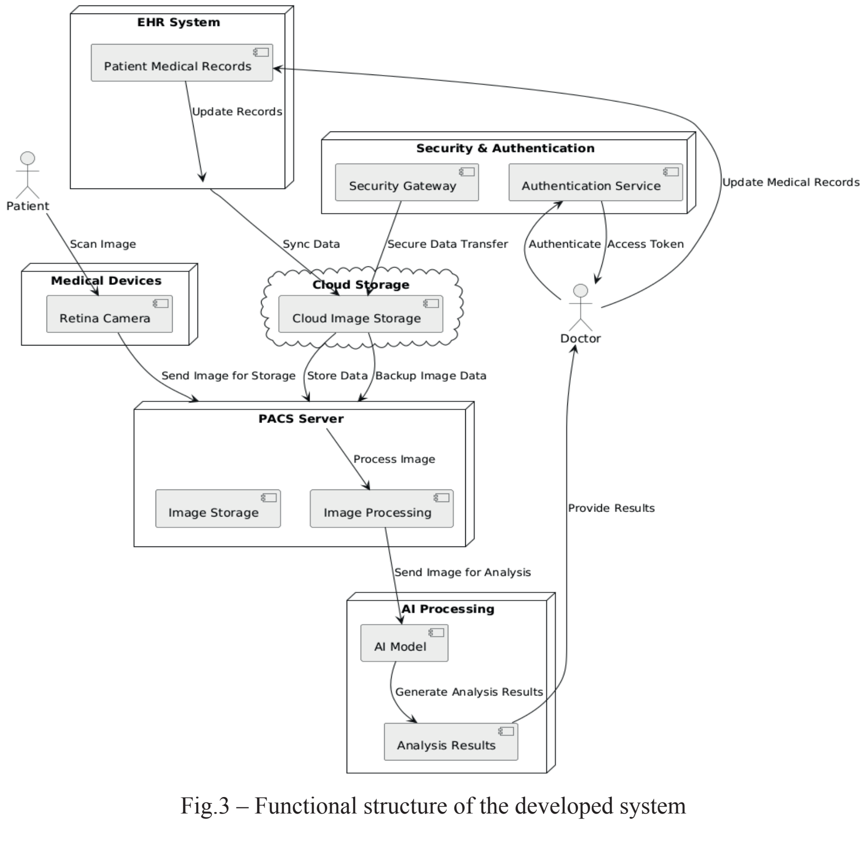

Fig.3 – Functional structure of the developed system

The placement of the *Doctor* at the end in the sequence of interactions is meant to reflect the flow of the system, where the *Doctor* typically interacts with the system after the AI has processed and generated the analysis results. However, the doctor's role is critical throughout the process, so it is possible to reorder the diagram to better reflect the collaborative and ongoing role of the doctor.

Key Features:

1. Doctor-AI Feedback Loop: After receiving the analysis results, the Doctor can request further clarification or corrections from the AI Model. This allows the Doctor to verify or adjust the AI model's results.
2. Error Handling: If there is an error in the AI Model, it reports to Error Handling, which notifies the Doctor. This ensures that the system can manage any issues that arise in real-time.
3. Authentication and Secure Data Transfer: The Doctor authenticates themselves via the Authentication Service, and secure data transfer is ensured by the Security Gateway for both medical image and record updates.
4. Cloud Synchronization: After the Doctor updates the EHR, the data is synchronized with Cloud Storage for backup and future retrieval.

Here is an adjusted sequence of interactions with a more appropriate flow:

1. The Patient scans their retina using the Retina Camera.
2. The Retina Camera sends the image to the PACS Server for storage.
3. The image is processed by the PACS Server.
4. The processed image is sent to the AI Model for analysis.
5. The AI Model generates the Analysis Results, which are sent to the Doctor for review and decision- making.
6. The Doctor reviews the results, diagnoses the patient, and updates the EHR System with the diagnosis and medical records.
7. The Doctor authenticates themselves via the Authentication Service to access the system.
8. The EHR System synchronizes the data with Cloud Storage for backup and long-term storage.
9. The Security Gateway ensures secure data transfer between components.

Main content. *Development of Information System Architecture: Data Management Platforms and Experimentation.* In this section, we delve into the experimental aspects of developing an AI-driven information system architecture, with a focus on Data Management Platforms (DMPs). These platforms form the backbone of the architecture, enabling the storage, retrieval, and processing of large volumes of healthcare data. The integration and testing of DMPs within the proposed architecture highlight their critical role in ensuring the system's efficiency and reliability.

Key Functions of DMPs in Healthcare:

- Data Storage: Secure storage of electronic medical records (EMRs), imaging data, laboratory results, and unstructured clinical notes.

● Data Integration: Unifying disparate data sources such as hospital information systems (HIS), wearable devices, and telemedicine platforms.

● Real-Time Data Processing: Enabling near-instantaneous analysis for real-time monitoring and diagnostics.

● Scalability: Supporting growing data volumes as healthcare institutions expand or adopt new AI tools.

Table 4 – Key Concepts, Definitions, and Technologies in Data Management Platforms for Healthcare

Concept	Definition	Key Technologies
Data Storage	Secure storage of structured and unstructured healthcare data.	NoSQL, Hadoop, Relational Databases
Data Integration	Combining data from multiple sources into a unified system.	ETL Tools, Apache Kafka, MuleSoft
Real-Time Processing	Processing and analyzing data as it is generated for immediate use.	Apache Spark, Stream Processing Frameworks
Scalability	Ability to handle growing data volumes without performance loss.	Distributed Databases, Cloud Platforms
Data Security	Ensuring compliance with data protection regulations and safeguarding patient data.	Encryption, Anonymization Tools
Interoperability	Facilitating seamless data exchange between different systems using standards like FHIR.	FHIR, HL7 Standards, Middleware
AI Integration	Embedding AI tools into the system for predictive analytics and diagnostics.	TensorFlow, PyTorch, Pre-Trained Models

Information System Architecture (ISA) development increasingly relies on robust Data Management Platforms (DMPs) to ensure effective data handling, storage, and analytics. Experimentation plays a crucial role in refining and validating these systems to align with organizational objectives.

This diagram in the following Fig.4 represents a sequential process of implementing artificial intelligence (AI) in eye care institutions. It is made in the format of a UML activity diagram and describes the main stages, starting from data collection and ending with the evaluation of the system's effectiveness. Each stage is accompanied by a short description indicating its content and purpose. *Data-Driven Approaches to Telemedicine and AI in Retinal Healthcare in Kazakhstan.* Digital health technologies provide transformative opportunities for addressing diabetic retinopathy (DR), one of the leading causes of preventable blindness worldwide. In Kazakhstan, where diabetes affects approximately 8% of the adult population (IDF Diabetes Atlas, 2021) and over 40% of residents live in rural areas, access to specialized ophthalmologic care remains limited. The integration of telemedicine, artificial intelligence (AI), and portable diagnostic devices offers significant potential to bridge these gaps in care delivery.

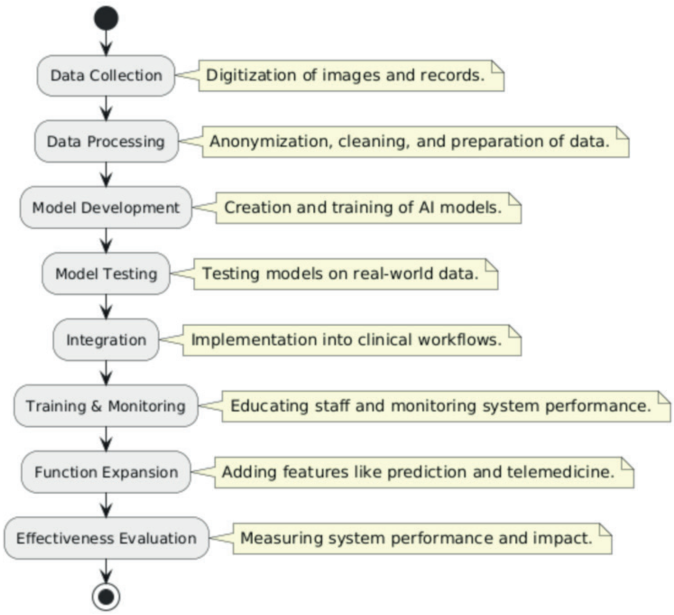

Fig. 4. – Sequential Workflow for AI Implementation in Eye Institutes

Telemedicine. Telemedicine has proven effective in large-scale DR screening programs globally, such as the UK's initiative, which achieved an 80% screening coverage among diabetic patients. This approach reduced blindness rates in the working-age population for the first time in 50 years. Kazakhstan could replicate this success through mobile diagnostic units equipped with fundus cameras, enabling the screening of up to 2 million individuals annually in rural and underserved areas.

Artificial Intelligence. AI algorithms, including systems like IDx-DR and EyeArt, have demonstrated a sensitivity of up to 96% and specificity of 93% in identifying referable DR cases. These tools can alleviate the burden on Kazakhstan's healthcare system, where only about 1200 ophthalmologists serve the entire population. Local adaptation of AI models, incorporating regional health data, could further enhance diagnostic precision and scalability.

Portable Diagnostic Devices. Cost-effective and portable retinal cameras, such as smartphone-based systems, provide practical solutions for rural screening programs. Devices like Fundus on Phone, costing around $5000, can replace traditional, expensive tabletop setups, significantly expanding coverage. Implementing these devices in primary care facilities across Kazakhstan could address the needs of approximately 70% of rural residents with limited access to eye care.

Remote Monitoring. Home-based monitoring systems, such as OCT devices, allow chronic DR patients to manage their condition effectively. These technologies could reduce the need for in-person visits by 30-50%, which is particularly beneficial for patients in Kazakhstan's remote regions. They could also improve outcomes for approximately 50,000 individuals requiring regular retinal monitoring.

Potential Outcomes. The deployment of these digital innovations in Kazakhstan could:

● Increase access to retinal care for over 4 million rural residents.

● Reduce the prevalence of late-stage DR complications by 20-30% through early detection.

● Lower healthcare costs by 15-20% by minimizing hospitalizations and expensive interventions.

● Enhance patient satisfaction and outcomes through improved accessibility and care quality.

Kazakhstan can leverage global advancements in digital health to transform its retinal care landscape. Telemedicine, AI, and portable technologies could collectively address the challenges of accessibility, scalability, and resource constraints. Their successful integration will require coordinated efforts from policymakers, healthcare providers, and technology developers, ensuring sustainable solutions tailored to the country's unique needs.

Results and discussion. *Key Benefits of AI and Telemedicine in Healthcare Information Systems***.** The developed information system architecture for healthcare, based on Data Management Platforms (DMPs) and artificial intelligence (AI) tools, has demonstrated its effectiveness in addressing key challenges:

● Optimizing data storage, integration, and real-time analytics of large medical datasets.

● Enabling accurate diagnostics using machine learning algorithms and real-time data processing capabilities.

● Improving access to quality healthcare services through the integration of telemedicine and portable diagnostic devices, especially in rural and remote areas.

● Ensuring compliance with international data security standards (GDPR, HIPAA), facilitating secure management of patient confidential data.

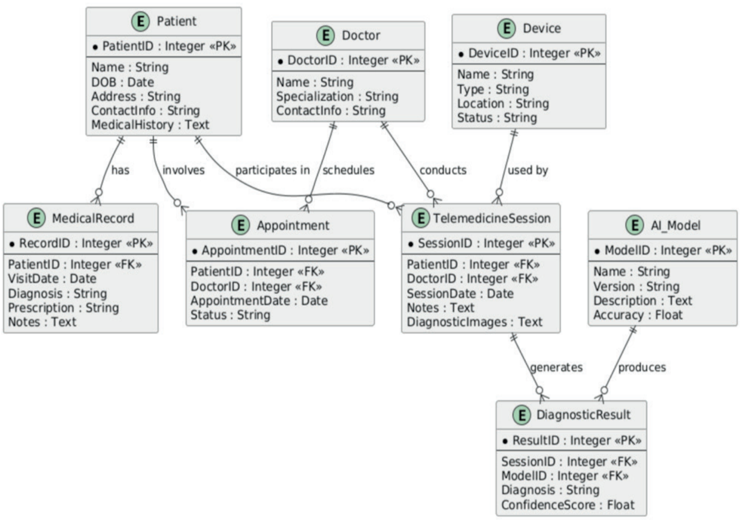

Fig. 5. – AI-Driven Telemedicine Architecture for Healthcare Systems

The ER diagram represents the entities and relationships in an AI-driven healthcare information system, focusing on telemedicine and patient management.

Entities:

1. *Patient:* Stores patient details (ID, name, medical history).
2. *Medical Record:* Stores patient medical data (diagnosis, prescriptions).
3. *Doctor:* Healthcare professionals (ID, name, specialization).
4. *Appointment:* Scheduled consultations (patient, doctor, date).
5. *Telemedicine Session:* Virtual consultations (patient, doctor, session details).
6. *AI Model:* AI algorithms for diagnostics (model name, accuracy).
7. *Diagnostic Result:* AI analysis results (diagnosis, confidence score).
8. *Device:* Medical devices used in telemedicine sessions.

Here is a table summarizing the benefits of the AI-driven information system architecture for healthcare:

Table 5 – The benefits of the AI-driven information system architecture for healthcare

Aspect	Benefits
For Patients	- Improved access to healthcare, especially in rural and remote areas.
	- Early diagnosis of conditions like diabetic retinopathy, reducing complications and blindness.
	- Remote health monitoring, saving time and resources.
For Healthcare Institutions	- Reduced workload on healthcare professionals through automation and AI tools.
	- Streamlined workflows via data integration across multiple systems.
	- Cost savings by minimizing hospitalizations and expensive interventions.
For the Healthcare System	- Scalable solutions for handling growing data volumes without performance loss.
	- Closing the healthcare service gap between urban and rural areas.
	- Increased healthcare quality and patient satisfaction.
For Global Healthcare Transformation	- Enables the application of AI and telemedicine in diverse medical fields (oncology, cardiology, etc.).
	- Contributes to the digital transformation of global healthcare systems.

This Tab.5 presents the main benefits for different stakeholders and the overall healthcare system.

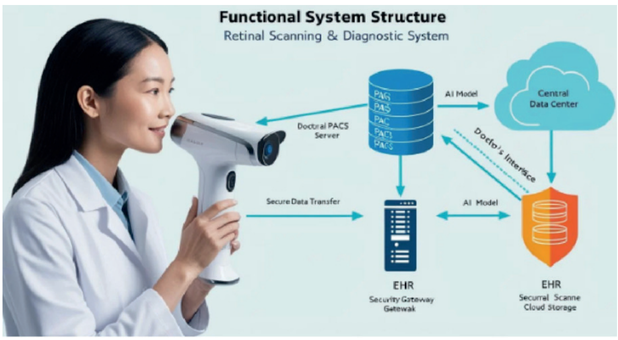

Fig. 6. – Integrated Diagnostic Flow in Healthcare System

This retinal scanning and diagnostic system represent an integration of advanced telemedicine technologies, artificial intelligence, and cloud computing, aimed at improving accessibility and efficiency in ophthalmological care. The architecture's core lies in data processing on the PACS server and analysis using artificial intelligence models, enabling highly accurate diagnostics with minimal specialist involvement. Ensuring secure data transmission and storage through a security gateway and cloud infrastructure complies with international standards such as GDPR and HIPAA, which is crucial in the context of healthcare digital transformation. The implementation of such a system can not only significantly reduce the burden on medical institutions but also eliminate barriers to quality medical care for residents in remote regions, making it a vital element of modern healthcare IT infrastructure Fig.6.

Conclusion. This work proposes a structural framework integrating telemedicine, AI, and portable diagnostic devices to improve healthcare accessibility in Kazakhstan. It bridges rural-urban gaps through virtual consultations, utilizes localized AI for precise diagnostics, and deploys cost-effective portable tools for real-time data collection. With GDPR and HIPAA-compliant data security and a modular, scalable design, the framework enhances accessibility, efficiency, and adaptability in underserved areas. In this work, we propose a framework integrating telemedicine, AI, and portable diagnostic devices to improve healthcare accessibility in Kazakhstan, particularly in rural and underserved areas. The framework leverages telemedicine to connect patients with specialists, AI models to automate and enhance diagnostic accuracy, and portable devices to enable real-time data collection and transmission. Secure data management compliant with GDPR and HIPAA ensures patient confidentiality, while the modular design allows for scalability and future expansion. Addressing challenges such as infrastructure limitations and personnel training is essential for effective implementation and long-term success.

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