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Analysis of the current state of computer systems in the field of virtual healthcare

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Abstract. The purpose of this study was to develop a conceptual model for the integration of modern digital technologies in the healthcare sector with adaptation to Ukrainian conditions and the creation of a single national medical ecosystem. The study was based on a systematic analysis of literature sources using content analysis and a systematic approach. Publications, review papers, and official documents available in leading scientific databases (PubMed, Scopus, and Web of Science) over the past five years were used to collect data. The research algorithm included preliminary selection of sources according to the criteria of relevance, reliability, and scientific significance, further analysis of technological solutions in the areas of telemedicine, artificial intelligence and virtual reality, and assessment of their integration compatibility with existing electronic health systems. The analysis covered the economic, ethical, and legal aspects of implementing innovative technologies. The results showed that telemedicine contributes to improving access to health services in remote regions, but its implementation is limited due to imperfect infrastructure and the lack of uniform regulatory standards. Analysis of artificial intelligence algorithms has shown their high potential in diagnosing and predicting diseases, which indicates the need to adapt technologies to local conditions. Research on the possibilities of virtual reality has confirmed its effectiveness in therapy, rehabilitation, and medical education, although implementation is accompanied by technical difficulties. The developed conceptual model considers both technical and organisational factors of digitalisation of healthcare, which can become the basis for strategic planning of further experimental implementations in the national health system. Thus, the analysis identified the main trends and problem areas of digital technology implementation that contribute to improving the quality of medical services and optimising resources. The results of the study form the scientific basis for developing practical measures and strategies for digitalisation adapted to the conditions of Ukraine

Keywords: telemedicine; virtual reality; artificial intelligence; privacy of medical data; digital transformation

Introduction

21st century medicine is at the stage of comprehensive digital transformation, which involves the active introduction of telemedicine, artificial intelligence (AI) and virtual reality (VR) in various areas of healthcare. These technological solutions not only improve the accuracy of diagnosis and effectiveness of treatment, but also significantly expand the possibilities of rehabilitation and remote monitoring of patients, especially in remote regions.

Thus, E. Donnellan & A. Watts (2024) noted that telemedicine has proved extremely important in times of crisis and emergency situations due to timely remote consultations and automated patient monitoring systems. In their publication, the researchers detailed the experience of using telemedicine solutions during disasters and epidemics, showing how they help to ensure continuity of medical care. The paper also emphasised the positive impact of such technologies on optimising resource allocation and improving interaction between doctors. However, W. Febriyani *et al.* (2023) emphasised that the lack of uniform data security standards and regulation of the legal framework hinders the large-scale spread of such solutions. The researchers proposed the development of unified information exchange protocols to strengthen patient privacy protection and prevent confidential data leakage. In addition, they stressed the importance of international cooperation in the harmonisation of legislative requirements and relevant ethical standards.

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Artificial intelligence algorithms are becoming increasingly important in the medical field, because they can quickly process large amounts of data and detect pathologies with high accuracy. V. Pillai (2024) drew attention to the fact that platforms like PathAI speed up diagnosis, but there is a question of transparency of the "black box" – difficulties in understanding exactly how the algorithm makes decisions in specific clinical cases. The researcher also suggested integrating explanatory AI techniques to increase trust on the part of doctors and patients and make the decision-making process clearer. N. Shah (2024) saw the need for clear standardisation of approaches and certification of AI tools, so that the results of their study are reproducible in various medical institutions. The researcher compared the available standards and proposed creating unified criteria for evaluating the accuracy and reliability of AI solutions. The researcher also noted that constant monitoring of algorithms and updating their models is a prerequisite for maintaining a high quality of medical services.

An equally important role was played by virtual reality, which opens up new prospects in therapy and rehabilitation, providing manageable conditions for training patients with various diagnoses. K. Moulaei *et al.* (2024) pointed out the effectiveness of VR platforms in dealing with post-traumatic stress disorder and the consequences of neurological damage, as patients are able to safely handle stressful situations or restore lost skills. The study noted that regular use of VR technologies contributes not only to improving clinical indicators, but also to increasing the motivation of patients to actively participate in their own rehabilitation. Moreover, interactive simulations have become useful for medical education, as they provide close to real-world clinical scenarios where students and doctors can hone their professional competencies (Schiza *et al.,* 2019). The researchers noted that such training significantly improved the skills of teamwork, decision-making in stressful conditions and mastering emergency protocols. It was based on simulating various situations in a virtual environment that participants were able to quickly respond to complications and mistakes, without exposing real patients to risks.

The next level of digital medicine is associated with building a single integrated environment where all stakeholders interact – from healthcare institutions and insurance organisations to patients themselves. According to S.S. Albouq *et al.* (2022), the fragmentation of available solutions and the lack of agreed protocols complicate data exchange and interoperability of systems, and therefore hinder the development of an integrated digital ecosystem. The researchers emphasised that the introduction of generalised standards can minimise duplication of processes and speed up the provision of health services at all levels. Instead, creating a shared information space could increase the effectiveness of therapy, optimise costs, promote better communication between doctors and patients, and simplify the implementation of synergy between AI, VR, and telemedicine services (Morita-Jaeger *et al.,* 2024). Researchers studying this topic emphasised that a single integrated platform can provide comprehensive support for clinical solutions and speed up administration processes. Attention has increased to ethical issues related to the confidentiality of personal data, and the distribution of responsibility for errors that can be made by automated systems. Therefore, the purpose of the theoretical research was to thoroughly investigate the available digital solutions and develop a conceptual model outlining scientifically based approaches to their implementation in broad clinical practice.

Materials and Methods

The study focused on the development and theoretical substantiation of a conceptual model that integrates key digital technologies and their interaction mechanisms in a single healthcare ecosystem. At the first stage of the study, a comprehensive analysis of scientific publications, review papers and official documents covering the implementation of telemedicine, artificial intelligence technologies, and virtual reality in various clinical settings was carried out. This approach helped to identify common patterns and the main challenges that arise when integrating individual digital solutions into medical practice. The accumulated information about real cases and implemented developments formed the basis for building a conceptual model.

In the process of forming the model, general scientific methods of data analysis, synthesis, and systematisation were used. Initially, the available sources were divided into thematic blocks covering specific areas of healthcare digitalisation. After summarising the results obtained, a search was carried out for logical connections between various technological solutions, which helped to identify critical nodes of the ecosystem that should be given special attention to ensure compatibility and scalability of the system. Special emphasis was placed on integrating electronic health records with a common database, which ensures continuous exchange of information between all components of the model. The analysis considered both technical and organisational aspects that contribute to the creation of an effective digital ecosystem in the context of modern clinical processes. To test the viability of the developed concept, an additional theoretical analysis of modern technological solutions used in medical institutions and research centres was carried out.

The study covered data encryption, security of information exchange, and effective integration of various information systems into a single digital healthcare platform (Pawar *et al.,* 2024). Special attention was also paid to the investigation of the possibilities of creating virtual environments for rehabilitation activities and training simulations.

A conceptual model has been developed that describes a complex architecture in which telemedicine, AI, and VR can interact through a single centralised data ecosystem. This model has been expanded with a more detailed description of information flows and possible connection points for other compatible technologies, such as Internet of Things systems for continuous monitoring of health indicators. Based on this, a number of recommendations were proposed to optimise the integration process, in

particular, to strengthen the security of data exchange, improve the compatibility of various electronic systems, and create common standards.

Results and Discussion

Overview of digital technologies in healthcare: Essence, significance, and key aspects

During 2014-2024, digital technologies were considered as a fundamental catalyst for the transformation of the healthcare industry, as they allowed expanding the horizons of diagnosis, therapy, and prevention. However, their massive development was accompanied by a number of challenges covering both legal and ethical issues, including the need to adapt infrastructure and improve the digital literacy of patients and healthcare professionals. Table 1 provides a comparative description of the main digital technologies that were actively used in medicine in 2024 and their key advantages.

***Table 1**. Key digital technologies in healthcare: features and advantages*

Technology	Description	Features and advantages
Telemedicine	Video consultations and remote medical care.	1. Provides access to medical services without physical contact. 2. Facilitates access for patients in remote regions. 3. Reduces the burden on inpatient departments and hospitals.
Artificial intelligence	Use of algorithms and machine learning to analyse medical data.	1. Improves the accuracy of diagnostics, in particular, in oncology and cardiology. 2. Can analyse large amounts of data to detect patterns and anomalies. 3. Automates routine tasks and improves the efficiency of healthcare professionals.
VR	Use of simulations for therapeutic or rehabilitation purposes.	1. Helps patients with mental disorders through exposure therapy (for example, schizophrenia, post-traumatic stress disorder). 2. Used in rehabilitation after injuries and strokes. 3. Creates opportunities for training medical personnel through simulations of complex clinical situations

***Source:** compiled by the author based on D.K Pawar et al. (2024)*

However, the large-scale integration is still accompanied by financial, technical, and personnel obstacles. If it is possible to develop more affordable equipment, uniform standards for testing effectiveness, and train the necessary specialists, virtual reality may well become an integral part of modern medicine. Table 2 summarises the main factors that facilitate or, conversely, restrain the introduction of digital technologies.

***Table 2**. Factors of introduction of digital technologies in medicine*

Factor	Impact on implementation	Detail
Technical standards	Lack of uniform standards can complicate integration and interaction between different technologies and platforms	1. Need to develop a single protocol for data exchange between medical institutions. 2. Importance of creating standards to ensure compatibility between different hardware and software solutions.
Legal aspects	Need to develop legal norms for the protection of medical data and define the limits of responsibility for their processing	1. Defining the legal framework for processing patients' medical data, especially in the context of telemedicine and AI. 2. Need to create rules for informed consent of patients to use their data for AI training.
Digital patient literacy	Low levels of digital literacy limit patients' access to new technologies and can become a barrier to their implementation	1. Patients who are not familiar with digital technologies may have difficulty accessing online counselling or health services 2. Problems with teaching patients the basics of using technologies such as video communication, online consultation platforms
Financing and investment	The need for large investments to create and maintain medical technologies, which may limit their implementation in some countries.	1. Develop infrastructure for digital medical platforms, including hardware, software, and staff training. 2. Government or private sector support is required to finance projects that reduce the cost of technology
Training of medical personnel	Regular training and retraining of healthcare professionals is required to effectively use new digital tools	1. Without proper training, doctors will not be able to effectively use new technologies, which will lead to their inefficiency. 2. Organisation of advanced training courses for medical professionals, which will ensure the correct use of technologies.
Social acceptability	Importance of cultural, social, and psychological aspects for the successful adoption of new technologies by patients and doctors	1. Patients, especially the older generation, may not be ready to use digital technologies such as video consultations 2. Consideration of socio-cultural features in the development of platforms and ensuring access to technologies for different groups of the population

***Source:** compiled by the author*

As evidenced by the experience of India and South Korea, given in the papers by N. Viswanadham (2021) and H.Y. Lee *et al.* (2023), comprehensive implementation of solutions is possible only with an interdisciplinary approach and coordinated actions of government agencies, medical institutions, IT companies, and insurance organisations. India has demonstrated an example of centrally combining hospitals, insurance companies and pharmaceutical suppliers into a single network that facilitates data access and treatment coordination. This model is especially

valuable for regions with uneven distribution of resources, where there are not enough specialists and modern equipment. South Korea focuses on personalised strategies where Internet of Medical Things (IoMT) devices continuously collect vital data and transmit it to the shared medical space. Due to this, doctors can quickly respond to minor deviations, which reduces the number of exacerbations and hospitalisations and increases patient comfort.

The combination of telemedicine, AI, and VR in a single platform forms the basis for future medicine based on continuous information exchange, personalisation of therapeutic programmes, and a multidisciplinary approach. As noted by W. Huang *et al.* (2023), AI systems can speed up the processing of laboratory tests, minimise errors, and support more efficient use of clinic resources. However, telemedicine and VR open up new formats of rehabilitation, when patients are given the opportunity to perform exercises remotely or undergo training scenarios. Despite their high potential, the integration of these tools largely depends on the degree of interaction between the state and the private sector, the willingness to invest in infrastructure and implement data protection measures. In addition, the lack of uniform industry standards and clear legal norms complicates the exchange of medical information, increases the risk of abuse or cyber-attacks, and undermines patient trust.

It is indisputable that digitisation of the medical sector has both social and economic consequences. South Korea's experience shows that the development of telemedicine and IoMT reduces barriers to access to qualified care, especially for remote regions or low-mobility patients (Lee *et al.,* 2023). This helps to improve public health indicators and allows doctors to focus on more complex clinical situations. From an economic standpoint, automating processes (such as laboratory research) using AI increases productivity and reduces the cost of manual work (Huang *et al.*, 2023). Telemedicine reduces the number of face-to-face visits, which reduces the need to expand the physical network of hospitals and allows doctors to serve more patients online. However, the success of such models is impossible without initial investment in equipment, training, and support for network infrastructure, and for poorer countries, these costs can be excessively high without external funding.

In addition, digital medicine can deepen social inequality if some people do not have access to high-speed Internet or the necessary level of technical skills. Therefore, state and international programmes of "digital inclusion" are becoming very important, aimed at ensuring that the most vulnerable categories of the population are not left out of medical innovations. Digital technologies in healthcare (telemedicine, AI, VR, and IoMT) have huge potential to improve the efficiency, accessibility, and personalisation of healthcare services. However, their large-scale implementation faces a number of obstacles – from the lack of unified technical standards and legal mechanisms to the problem of insufficient digital literacy. Successful integration of these technologies into the real medical ecosystem requires:

1. Systematic approach that considers telemedicine, AI, VR, and IoMT as an interconnected ecosystem. All components must be compatible with each other and based on agreed standards for storing, sharing, and analysing medical data.

2. Interdisciplinary interaction that attracts specialists in the fields of medicine, computer science, engineering, and social sciences. This helps to assess the impact of digital solutions on different regions and health systems, considering economic, cultural, and legal characteristics.

3. Legal and ethical grounds. Clear regulatory norms and mechanisms of responsibility in case of errors or abuses are needed, in particular, regarding the processing of personal data and explaining the results of AI systems.

4. Comprehensive training programmes for doctors and patients, and digital inclusion efforts to avoid the gap between "technologically trained" and vulnerable populations.

5. Financial incentives and public-private partnerships to cover high initial costs and further scale pilot projects to the level of national programmes.

If these principles are followed, digital innovations can move from the category of auxiliary or "crisis" tools to a full-fledged basis for the development of modern healthcare. In the long run, this can ensure better provision of medical services, save resources, and develop truly patient-centred medicine, where everyone receives the necessary care on time and in a convenient format.

Telemedicine: Integration in the modern healthcare system

In the period 2015-2024, telemedicine became particularly important as one of the most promising tools for modernising the healthcare sector. It significantly reduced the physical distance between the patient and the doctor, providing virtual consultations, diagnostics, and real-time monitoring. According to M. Hägglund *et al.* (2023), in the context of the COVID-19 pandemic, the introduction of video consultations in the Swedish primary care system has reduced the burden on inpatient departments and reduced the risk of infection of people from high-risk groups. However, such a rapid transition required not only the installation of technical equipment, but also a significant restructuring of infrastructure, which in some regions was not properly developed. In addition, information campaigns were conducted to dispel patients' scepticism about the safety and effectiveness of online interaction.

L. Kupczik *et al.* (2022) and M.S. Khan *et al.* (2019) noted that video consultations are only the initial stage in the development of telemedicine. A promising area is the widespread introduction of remote sensors that can transmit real-time data on the patient's physiological state (blood pressure, pulse, oxygen saturation, etc.). This format allows quickly identifying deviations and adjusting therapy, which is especially important for patients with chronic diseases (cardiovascular, respiratory, etc.). However, the researchers warn about the risks of leakage of confidential information, since data transmission can take place through different platforms with different levels of protection. This makes it

difficult to form a unified picture of the course of the disease and disrupts the continuity of patient monitoring. An equally important aspect is the development of universal technical protocols that allow integrated data exchange between medical institutions. Unification of formats and standards facilitates interaction between doctors, reduces barriers to patient performance transmission, and improves treatment coordination. It is necessary to clearly distribute the levels of access to medical records to protect personal data and prevent unauthorised use of information. The imperfection of the legal framework in this area often becomes a serious obstacle to the development of telemedicine, even despite the obvious advantages of such a model.

As noted by Y. Sofia *et al.* (2022), telemedicine also carries socio-cultural challenges. Remote consultations have greatly facilitated access to a doctor for those who live in remote regions or have limited mobility. However, older adults and patients with low levels of digital literacy may have significant difficulties adapting to technological innovations. To overcome this barrier, comprehensive educational initiatives, training programmes on the use of telemedicine services, and the involvement of social workers to help set up video communications and explain what data the doctor needs are offered. All this shows that for the full integration of telemedicine into the healthcare system, it is necessary not only to improve the technical base, but also to build patient trust and ensure the protection of personal data. In general, telemedicine is turning from an "emergency" tool into a full-fledged component of modern medical care. Its greatest potential is manifested in epidemiological threats, when it is important to minimise contacts in hospitals and simultaneously maintain the continuity of service provision to a wide range of the population. The history of remote consultations and access to digital patient cards greatly facilitate the work of various specialists, because all information is available in a centralised format. However, the ultimate success of spreading such models depends on the availability of clear technical solutions, public confidence in online doctors, and high-quality support for patients who need help using new services.

Artificial intelligence in medicine: Application and problems

AI is rapidly integrating into medical practice, as it can process big data, identify hidden patterns, and improve diagnostic accuracy. According to the observations of O.C. Oguine & K.J. Oguine (2022) and J. Li *et al.* (2024), deep learning algorithms are very effective in recognising the first signs of cancer in medical images. This is extremely important for oncology, since early detection of the disease allows choosing the optimal therapy in time and thereby increasing the chances of recovery. Based on AI, doctors can reduce the impact of the human factor and pay more attention to complex clinical decisions, rather than routine verification of results.

A. Amjad *et al.* (2023) highlighted the growing efficiency of AI through its combination with IoMT. This integrated environment allows continuously monitoring patients' vital signs and instantly signalling deviations from the norm. This paves the way for a preventive model of medicine, where exacerbations can be avoided or postponed to a later date due to timely treatment adjustments. However, the effective implementation of these ideas requires the unification of information platforms and security protocols to protect sensitive data and eliminate duplication of information in different databases (Mohammed *et al.,* 2022).

M.S. Khan *et al.* (2019) focused on the compatibility of different information systems, without which AI algorithms will not be able to form a holistic view of the patient's condition. Disparate databases, lack of a consistent format for storing information, and duplication of records increase the risk of clinical errors and delay treatment decisions. Therefore, the inclusion of AI in the infrastructure of medical institutions requires not only technical, but also organisational training, including the establishment of procedures for the exchange of medical information. The phenomenon of the "black box" remains particularly controversial, when the decision-making process of a neural network is incomprehensible to users. According to D. Apage (2023), this opacity creates distrust on the part of doctors and patients who do not know what factors influenced the diagnosis or recommendation. The answer to this problem is the explicable AI paradigm, which allows explaining how the algorithm came to a certain conclusion (Patil *et al.,* 2021). However, the introduction of such solutions requires additional developments and new methodologies for interpreting complex machine learning models.

From a legal standpoint, the question of liability for AI errors remains open. When the algorithm assumes inaccuracies in a complex clinical case, it is not clear who should be responsible – the doctor who trusted the technology, the software developer, or the institution that implemented it. Such aspects are actively discussed by legal experts, and relevant regulators who are trying to adopt rules for the use of AI. Thus, the success of AI in medicine depends not only on the quality of algorithms and the amount of data, but also on creating transparent rules and safety standards that establish a framework of responsibility and protect the interests of patients.

Virtual reality: Therapy, rehabilitation, and training

VR has opened up new approaches to treatment and rehabilitation, offering the creation of interactive environments that are as close as possible to real conditions. With VR, patients can "immerse themselves" in controlled scenarios that mimic social interactions, therapeutic exercises, or even critical situations that are not available for safe playback in a clinic setting. According to D. Kruk *et al.* (2020), the use of VR therapy has shown positive results in patients with psychiatric disorders, in particular, schizophrenia. This format allowed tracking reactions in more detail and gradually correcting pathological representations, avoiding excessive stress or risky contacts.

The study by M.M.T.E. Kouijzer *et al.* (2023), which was based on the North American Society for the Sociology of Sport (NASSS) Framework, highlighted several barriers to introducing VR into everyday practice. First, there are not enough specialists who have a thorough knowledge of clinical medicine and understand the development of virtual environments. Second, high equipment costs (helmets, controllers, powerful computers) hinder large-scale implementation. Third, the lack of proper facilities and the lack of understanding of the potential of VR by the management of institutions also make it difficult to integrate the technology. Z. Liu *et al.* (2022) summarised areas where VR has already demonstrated tangible positive effects: treatment of post-traumatic stress disorder (PTSD), treatment of various phobias (A&F), chronic pain management (PM), and dynamic neuromuscular stabilisation (DNS). The key advantage is the possibility of gradual exposure of the patient to trigger situations and the development of game scenarios that increase the motivation of patients for rehabilitation. However, the researchers emphasised the lack of unified methods for evaluating the effectiveness of VR therapy, which makes it difficult to compare the results of different research groups.

According to F. Ferreira-Brito *et al.* (2022), gamification is an important factor in increasing the attractiveness of VR applications. In virtual "gaming" environments, patients feel more involved and follow rehabilitation instructions more easily. However, the spread of such solutions is still hindered by the high cost of the hardware complex, the need for a high-speed Internet connection and the availability of technical personnel responsible for the correct operation of VR systems. Thus, despite the great prospect, VR continues to be a technology that requires further improvement and adaptation to the real conditions of various clinics. Overall, the analysis of these studies shows that VR can significantly expand the available therapy formats, increase patient motivation to collaborate with a doctor, and complement conventional treatment and rehabilitation methods.

Conceptual model for integrating digital technologies into the healthcare system

Based on the analysis and collected literature, a conceptual model for integrating digital technologies into the healthcare system was developed, which provides for the creation of a single integrated environment. This environment combines telemedicine services, artificial intelligence tools, virtual reality technologies, and other digital solutions, ensuring their synergistic interaction to improve the efficiency of medical services. The structure and interaction of system components is shown in more detail in Figure 1.

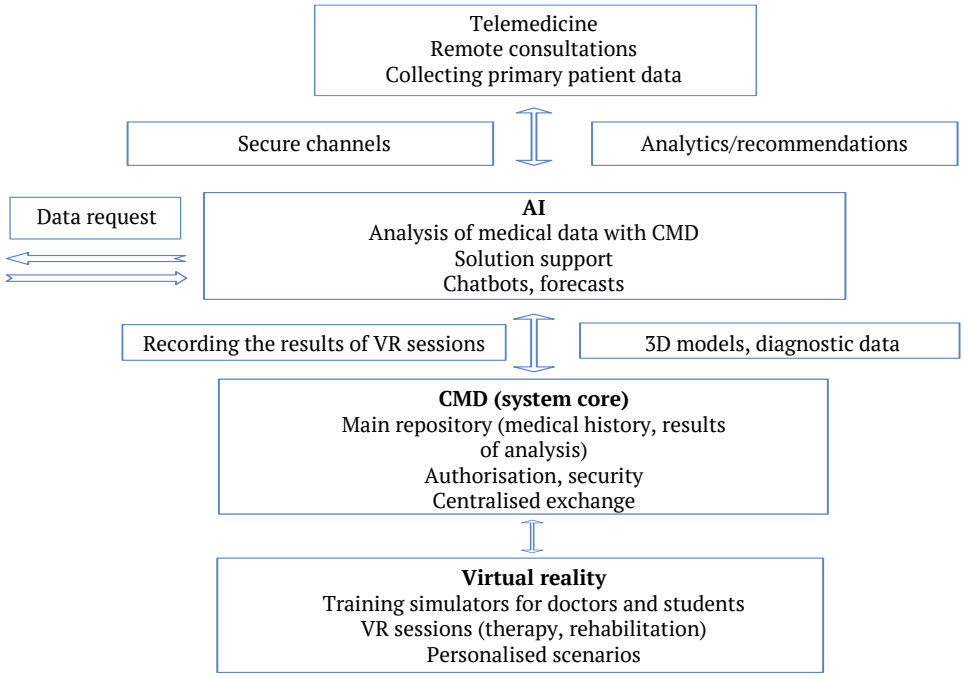

Figure 1. *Integrated medical ecosystem: telemedicine, AI, VR, and centralised database*
Source: *compiled by the author*

The basis of this integration is a centralised ecosystem of medical data that combines information from a variety of sources, including electronic medical records, data from telemedicine consultations, test results, and metrics collected using Internet of Medical Things. Such an ecosystem provides a continuous stream of data that is analysed using AI algorithms to support clinical decision-making, risk prediction, and treatment personalisation. The use of AI allows automating routine tasks, improving the accuracy of diagnostics and optimising treatment processes. For example, deep learning algorithms can quickly and accurately detect abnormalities in medical images, which

significantly speeds up the process of making a diagnosis and choosing the optimal therapy.

An important aspect is the use of VR technologies for patient rehabilitation and training of medical personnel. VR environments create a controlled and adaptive therapy environment, allowing patients to safely handle stressful situations or restore physical skills. For medical personnel, VR provides the ability to train in simulated clinical scenarios, which increases their professional competence and readiness for various clinical situations. For example, virtual simulations can help doctors to practice complex surgical procedures without risking patients, and patients with mental disorders can safely process their emotions in a controlled environment.

Telemedicine plays a key role in ensuring the availability of health services for patients in remote regions and for those with limited mobility. Remote monitoring of physiological parameters in combination with teleconferences allows doctors to constantly monitor the condition of patients and quickly respond to changes in their health. This not only improves the quality of medical services, but also reduces the burden on hospitals and medical institutions. For example, patients with chronic diseases can regularly receive remote consultations and monitoring, which allows them to adjust the treatment process in a timely manner and prevent complications.

Integration of digital technologies also involves considering regulatory aspects and issues of confidentiality of medical data. The implementation of common security standards and data exchange protocols is an important component for ensuring the protection of patients' personal information and responsibility for its processing. Regulating the legal framework promotes trust in digital medical solutions and their widespread adoption. For example, the creation of regulations on the collection, storage, and transmission of medical data, and defining the responsibility of the parties in the event of violations, is a necessary step to ensure the safety and effectiveness of digital medical systems.

The social and organisational aspects of digital integration include increasing digital literacy among patients and medical staff, and creating conditions for smooth interaction between different participants in the medical ecosystem. This includes conducting training programmes, information campaigns, and creating intuitive interfaces for users of different ages and social groups. Increasing digital literacy allows patients to use telemedicine services more effectively, and healthcare professionals to successfully integrate new technologies into their daily practices. For example, organising training sessions for doctors on the use of AI and VR can significantly improve the quality of medical services and increase patient satisfaction.

The integration of digital technologies into the healthcare system also requires consideration of economic aspects. High initial investment in equipment procurement, software development, and staff training can be a significant barrier for many healthcare facilities. However, the long-term benefits of implementing digital technologies, such as reducing the cost of maintaining physical infrastructure, improving the productivity of healthcare workers, and improving the quality of healthcare services, make this investment justified. For example, automating laboratory processes using AI can reduce the cost of processing tests and improve the accuracy of results, which, in turn, improves the efficiency of medical institutions.

Overall, the integration of digital technologies into the healthcare system provides a comprehensive approach that combines technical innovation, regulatory, social adaptation, and organisational support. This helps to create a flexible, efficient and safe medical ecosystem that can meet modern challenges and provide a high level of medical services for all categories of the population. Based on this integration, it is possible to achieve a more flexible, personalised and patient-oriented medicine that is able to quickly adapt to changes in the medical field and provide high-quality care regardless of the geographical location or socio-economic status of patients.

Challenges, prospects, and ethical aspects of implementing digital technologies in the medical sector of Ukraine

The introduction of digital tools in Ukrainian medicine faces a number of fundamental obstacles, while opening up significant prospects for improving the quality and accessibility of medical care. One of the most important factors that complicate the implementation of these processes is the lack of funding. Against the background of military operations, the country is forced to allocate limited resources primarily to the needs of the defence complex and the provision of urgent social programmes. As a result, funds aimed at modernising medical infrastructure and developing/implementing the latest software are often not enough. This situation directly affects the availability and quality of telemedicine services. According to the latest statistics, only 8% of doctors use specialised official telemedicine platforms that require a paid subscription or installation of additional applications. But the popular free messengers Viber, Telegram, and WhatsApp have become widespread. As noted by V. Poberezhets *et al.* (2022) despite their convenience and accessibility, these unofficial services do not provide the proper level of personal data protection and are not adapted to the systematic maintenance of electronic medical records. Accordingly, cyber risks and the likelihood of leakage of sensitive patient information are increasing, which is especially critical under martial law.

The second difficult problem is the insufficient level of digital literacy among both doctors and patients. It is interesting that experienced doctors with more than 10 years of experience in some aspects are more adaptive to the use of certain digital tools, compared to the younger generation of specialists, which, at first glance, should be more "technologically savvy". In particular, older doctors are more likely to master remote monitoring using blood glucose meters or pulse oximeters, while young specialists are often less knowledgeable in the field of telemedicine

and need specialised training (Kotsarenko *et al.,* 2023). This paradox is explained by the fact that traditional educational programmes for doctors in previous years could offer separate modules or courses related to the introduction of telemedicine technologies, while current university graduates do not always have the opportunity to receive such training in the proper amount. Therefore, the establishment of a programme of additional trainings, webinars, and courses for different age groups of health workers becomes a necessary condition to increase the overall level of digital competence and move the process of digitising healthcare from its place.

The third key aspect remains the lack of a proper regulatory framework. Despite the gradual progress, Ukraine still lacks clear legislative provisions that would regulate the collection, processing, and dissemination of medical data, and define standards for secure electronic document management. International law and European Union (EU) legislation in this area provide for rather high requirements for compatibility of IT systems, data encryption methods, and interaction procedures between different institutions. However, as of today, Ukrainian regulations do not always meet these requirements, creating legal uncertainty and holding back the potential for digitalisation. M. Kotsarenko *et al.* (2023) emphasised that without clear rules for the protection of medical records and without agreed mechanisms that would regulate the work with personal data, significant progress in the field of telemedicine remains problematic.

The use of the latest technologies, which include artificial intelligence and virtual reality, opens up unique prospects for reforming domestic medicine. Based on the conclusions of M. Kotsarenko *et al.* (2023), the use of AI has significantly improved the process of diagnosis and monitoring of patients' condition: automation of X-ray analysis, ultrasound diagnostics or computed tomography (CT) examinations simplifies and accelerates the detection of pathologies, and predicting the risks of complications allows the doctor to adjust treatment in time. This approach not only optimises time and financial costs, but also improves the accuracy of diagnoses, which is especially valuable during armed conflict, when the number of wounded and patients with serious injuries increases. VR technologies, in turn, prove their effectiveness in the rehabilitation of military and civilian victims of military operations. The ability to create interactive simulations allows performing recovery procedures remotely or speeding up the return to normal life after injuries. In addition, VR technologies can be integrated into the training system for future doctors: creating virtual clinical cases and training scenarios allows students to acquire practical skills without risks for real patients.

International cooperation is of great importance for accelerating the digital transformation of Ukrainian medicine. Organisations such as the World Health Organisation (WHO), the World Bank, and the United States Agency for International Development (USAID) actively support modernisation projects in countries in conflict or with limited resources (Kruk *et al.,* 2020). Attracting external grants and technical assistance allows purchasing the necessary equipment for remote diagnostics, improving local telemedicine platforms, and organising large-scale training programmes for staff. Partnership with European states and organisations encourages the harmonisation of Ukrainian legislation with EU standards. This refers to personal data protection policies, cryptography, and information transfer protocols. All this generally increases the confidence of patients and doctors in innovative technologies, and creates a solid foundation for the legal use of digital tools. In the end, the international exchange of experience helps to find and adapt best practices from states that have already passed similar challenges, in particular, in the organisation of remote rehabilitation or psychological support for the population affected by military operations. Research has confirmed that the synergy of local specifics and global innovations allows quickly and effectively integrating advanced medical solutions into the reality of Ukrainian healthcare (Kotsarenko *et al.,* 2023).

However, along with these economic, organisational, and technical challenges, it is important to pay due attention to the ethical aspects of using digital tools in the medical field. Protecting patient privacy and privacy is becoming increasingly critical as the use of artificial intelligence, telemedicine, and robotic therapeutic technologies significantly increases the volume and speed of medical information processing. E. Chandrakar & A. Dahiya (2024) emphasised that it is necessary to create an effective legal framework that would clearly regulate the rules of access to data and prevent possible abuse by commercial structures or third-party organisations. They noted that the patient's informed consent to data processing and transparency of these processes are the cornerstone of trust in new technologies. Patients should know how and for what purpose their information is used, and be able to revoke permission to process it if necessary.

It is also important to ensure reliable cybersecurity in the field of robotic therapy and virtual psychotherapy. According to L. Grosman-Rimon & P. Wegier (2024), these industries collect particularly sensitive information related to mental and physical health, making it a potential target for cyber-attacks. The researchers stressed that technical security tools should be combined with clear incident response procedures to quickly identify the problem and minimise damage in the event of a data leak. They also stressed the importance of creating instructions that are accessible to patients themselves, so that the latter understand how their data is stored and who has access to it. The introduction of security standards for developers and providers of medical technologies, according to researchers, will help to prevent the implementation of unfair practices and strengthen the security of private information.

There are concerns about the depersonalisation of medical care, where excessive reliance on AI and digital algorithms can displace direct human contact. S.O. Hansson & B. Fröding (2024) warns that reducing the time a doctor

spends communicating with a patient can negatively affect the quality of treatment and the patient's emotional state. Socio-cultural factors also play a significant role: in different regions and among different population groups, the attitude to technology in medicine may differ significantly. Therefore, the introduction of AI should be accompanied by training programmes for doctors that explain the ethical and cultural aspects of using innovative solutions to prevent a decrease in the level of empathy and trust on the part of patients.

According to I.O. Bogomazova (2024), some of the problems related to the preservation of privacy can be solved by legislating the procedure for informed consent to the use of medical data for research or commercial purposes. Anonymisation of information that is necessary for training machine learning algorithms becomes particularly relevant. Care should be taken to ensure that anonymisation preserves the usefulness of data for researchers and does not interfere with scientific progress. The researcher pointed out that it is advisable to create independent regulatory bodies or structures that would conduct security audits and monitor compliance with established standards on the part of developers and suppliers of digital medical solutions. This approach will help maintain trust in medical institutions and individual specialists who directly use technological tools for treatment and diagnosis.

Thus, the Ukrainian healthcare system faces a number of fundamental challenges – from limited finances and uncoordinated legislation to a lack of digital literacy among doctors and patients. Despite this, the potential of technologies, in particular, telemedicine, AI and VR, remains extremely large. In the context of military operations and the difficulties associated with them, these solutions can serve as a basis for optimising resources, expanding access to quality medical care, and restoring the health of military personnel and civilians. However, the real benefit from the introduction of digital tools is possible only with systematic support from the state and active international cooperation aimed at forming the necessary legal, financial and educational foundations. An equally important component is ethical – the protection of confidential data and the preservation of the human face of medicine, where technology supports the doctor, and does not replace them. Only such an integrated approach will ensure an effective and secure digital transformation of the Ukrainian medical industry and help to strengthen its potential on the way to integration into the global medical space.

Key recommendations for digitalisation of healthcare

Considering the results of the study, a number of recommendations are proposed for further integration of digital technologies into the healthcare system, which will create a unified, efficient, and safe medical ecosystem. First, it is necessary to implement unified technical standards for the collection, storage, and exchange of medical data. Creating a single protocol will ensure compatibility between different information systems and devices, reduce the risk of data duplication, and facilitate prompt clinical decision-making. Second, legal regulation in the field of digital medicine should be strengthened. The development of clear regulations on the protection of personal information, defining mechanisms for liability for violations and setting standards for electronic document management will help not only to protect patients' data, but also strengthen the trust of both medical professionals and patients themselves in digital solutions. Third, special attention should be paid to improving digital literacy among medical personnel and users of medical services. The organisation of regular trainings, seminars, webinars, and courses on the use of digital technologies will help to reduce barriers to the introduction of innovative tools, allow doctors to use the capabilities of telemedicine, artificial intelligence, and virtual reality more effectively, and patients will be more confident in navigating new services.

An important component of the strategy is the promotion of interdisciplinary collaboration. Joint projects involving specialists in medicine, IT, engineering, and social sciences will contribute to the development and implementation of adapted innovative solutions that meet the specifics of modern healthcare challenges. Ultimately, financial support remains a critical factor. Actively attracting public resources, private investment, and international grant programmes will allow implementing large-scale projects to modernise medical infrastructure, ensure the purchase of modern equipment, and support constant software updates. An integrated approach, which includes the unification of technical standards, legal regulation, digital literacy, interdisciplinary interaction, and financial support, will become the basis for further digital transformation of healthcare and will contribute to the creation of a modern patient-oriented health care system.

Conclusions

As part of the study, a comprehensive analysis of digital technologies in the healthcare sector was carried out and a comprehensive conceptual model was developed that combined telemedicine solutions, artificial intelligence, virtual reality, and IoMT devices. Systematic study of scientific literature, detailed familiarisation with current innovations and methodological analysis of the collected data helped to achieve the declared goal. In the course of research, the advantages of each technological area were considered, key difficulties associated with their implementation were identified, and specific recommendations were formulated for optimising the interaction of all components within a single digital ecosystem.

The results confirmed that digital reform of the medical industry opens up new opportunities for improving diagnostics and treatment, in particular, through the active use of remote patient monitoring and automation of routine operations based on machine learning algorithms. The proposed conceptual model illustrates how a combination of telemedicine services, AI-based platforms, and virtual reality tools can improve the quality of healthcare

delivery by ensuring continuous data exchange between all healthcare participants. The practical value lies in creating a methodological basis for further implementation of integrated digital solutions both in clinical activities and in the modernisation of information systems of medical institutions. The proposed options for solving the problems of technology compatibility, legal regulation, and improving digital literacy provide the basis for more effective implementation of innovative approaches in the work of healthcare institutions. Further study involves conducting pilot projects to test the viability of the developed model in practice, and developing security standards and data transmission protocols. This will improve the concept itself, adapting it to the specifics of medical institutions in different regions, and guarantee reliable protection of personal information and stable quality of medical services.

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Conflict of Interest

None.

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Аналіз сучасного стану комп'ютерних систем в сфері віртуальної охорони здоров'я

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Анотація. Метою даного дослідження була розробка концептуальної моделі інтеграції сучасних цифрових технологій у сфері охорони здоров'я з адаптацією до українських умов та створення єдиної національної медичної екосистеми. Дослідження базувалося на систематичному аналізі літературних джерел із застосуванням контент-аналізу та систематичного підходу. Для збору даних використовувались публікації, оглядові статті та офіційні документи, доступні у провідних наукових базах даних (PubMed, Scopus, Web of Science) за останні п'ять років. Алгоритм дослідження включав попередній відбір джерел за критеріями актуальності, достовірності та наукової значущості, подальший аналіз технологічних рішень у напрямках телемедицини, штучного інтелекту та віртуальної реальності, а також оцінку їх інтеграційної сумісності з існуючими електронними системами охорони здоров'я. Аналіз охоплював економічні, етичні та правові аспекти впровадження інноваційних технологій. Отримані результати свідчили про те, що телемедицина сприяє покращенню доступу до медичних послуг у віддалених регіонах, проте її впровадження обмежене через недосконалу інфраструктуру та відсутність єдиних нормативно-правових стандартів. Аналіз алгоритмів штучного інтелекту засвідчив їх високий потенціал у діагностиці та прогнозуванні захворювань, що вказує на необхідність адаптації технологій до локальних умов. Дослідження можливостей віртуальної реальності підтвердило її ефективність у терапії, реабілітації та медичній освіті, хоча впровадження супроводжується технічними складнощами. Сформована концептуальна модель враховувала як технічні, так і організаційні чинники цифровізації охорони здоров'я, що може стати основою для стратегічного планування подальших експериментальних впроваджень у національну систему охорони здоров'я. Отже, проведений аналіз дозволив виявити основні тенденції та проблемні зони впровадження цифрових технологій, що сприяють підвищенню якості медичних послуг та оптимізації ресурсів. Результати дослідження формують наукову базу для розробки практичних заходів і стратегій цифровізації, адаптованих до умов України

Ключові слова: телемедицина; віртуальна реальність; штучний інтелект; конфіденційність медичних даних; цифрова трансформація