ARCHITECTURAL-TECHNOLOGICAL PRINCIPLES OF A PATIENT-CENTERED DIGITAL TWIN AND ITS VISUALIZATION ALGORITHM IN CLINICAL PRACTICE

Masuma Mammadova[1,], Zarifa Jabrayilova[1], Aytan Ahmadova[1]
•
[1]Ministry of Science and Education Republic of Azerbaijan, Information Technology Institute, Baku, Azerbaijan
mmg51@mail.ru , djabrailova_z@mail.ru , ayten.adia1996@gmail.com

Abstract

This article presents the essence and architectural-technological principles of digital twin technology, and presents an algorithm for creating a digital twin based on the visualization of medical data through Power BI. The digital twin supports the early prediction of diseases and the analysis of personalized medical indicators by simulating the human body and enabling real-time monitoring of the condition. The article proposes a generalized architecture for building a digital twin of the human body at the level of organs and relevant diseases, the stages of its formation, and develops a schematic description of a virtual object. The Power BI platform is chosen to visually present the virtual object update simultaneously with any changes occurring in the physical object, which is the main architectural component of the medical digital twin. As a real source of information, it is referred to the available national database where doctors periodically collect information about patients in traditional clinical practice. Dashboards are developed on the Power BI platform to form the trajectory of change of medical indicators based on their values given in a time series. The digital twin created based on this approach enables the real-time monitoring of dynamic changes in test results, which supports the acceleration of physician decision-making related to health condition management, the improvement of service quality, and the provision of more prompt and personalized patient care.

Keywords: digital technology, e-health data, digital twin, visualization, Power BI, digital twin dashboard.

I. Introduction

Nowadays, digital technology is applied in a complex and targeted manner in almost all areas of healthcare. Today it is possible to process heterogeneous health data in real time, whereas, previously, the generation, collection and joint processing of this data was time consuming and performed offline.

The acceleration of the trends in the use of digital technology expands its boundaries and possibilities, and accordingly, conditions the emergence of the phenomenon of "digital transformation". Digital transformation ensures the data transformation into information and knowledge and its use for effective decision-making based on the new knowledge acquired [1]. The digital twin (DT), one of the basic technologies of digital transformation, acts as a digital copy of the physical object or process they represent and enables their real-time monitoring and situation assessment, regardless of location [2].

The present article proposes an algorithm for creation of a DT based on the Power BI platform to visually present the essence, architecture of a medical DT and update of a virtual object.

II. Related work

In the 1950s, NASA (National Aeronautics and Space Administration), GE (General Electric) and other industrial manufacturers created abstract digital models of equipment to account for equipment productivity and life cycle through simulation modeling [3].

In 2002, DT was presented as a "virtual, digital equivalent of a physical object" [4], and proposed as a conceptual model based on Product Lifecycle Management (PLM). It was technologically extremely difficult and expensive to bring to the use. Ten years later, the rapid development of "big data", "Internet of Things" (IoT) and "Internet of Medical Things" (IoMT) technologies enabled the implementation of this idea. In 2010, Jon Vickers from NASA introduced the term "digital twin" to science. In 2014, the concept of "virtual digital equivalent of a physical product" was proposed by M. Grieves [5].

Combining sensor data, computer modeling and artificial intelligence algorithms, medical DT acts as a digital (virtual) mirror of the real object [6].

DT in healthcare is designed to provide more effective and flexible medical interventions, assisting physicians and medical staff to understand the patient's health status [7]. One of the main conditions for the application of DT in medicine is its real physical object. A medical DT is a dynamic digital model that contains all the information about a physical object or medical system.

Establishing a complete DT of healthcare is a long-term and multi-level process. The first, that is, the health level, includes medical activity, pharmacy and medical education. The second level is the subject level, which includes departments such as ambulatory care, emergency care, dentistry, drug production and drug sales. The third and fourth levels, respectively, consist of the creation of personalized (patient-centered) DT on individual human organs and diseases related to these organs [8].

The benefits of DT can be applied in disease treatment, health management and many areas of personalized medicine in the healthcare sector. DT can provide different treatment options for different patients with the same disease and accelerate the development of personalized medicine. The essence of patient-centered medicine is the individualization of drug therapy according to the personal data and genotype of a specific patient. These opportunities created by DT are very important in terms of providing medical services to patients, which is the main component of healthcare. By transferring the patient's physical characteristics and health data to the digital environment, DT offers innovative solutions in determining the accurate diagnosis and treatment process, as well as in the formulation of personalized medicine. Digital twins of the human body are built to model its organs, cells, individual genetic composition, physiological characteristics and habits (lifestyle) of each person, and enable the creation of individual drugs and treatment plans [9]. These copies (the digital patient), which are the internal subsystems of the human body as a whole, can improve healthcare and patient care by personalizing diagnostics.

Medical digital twins can be used to solve the following problems for the formulation of personalized medicine:

- making an early diagnosis at the initial stage of the disease;
- monitoring of further development trajectories of the disease;
- optimizing the time of medical aid;
- improving personalized medicine;

• clarifying the mechanisms of drug action on the patient, etc.

Along with listed solutions, DT allows to test and visualize relevant results and predict dynamic variables [10].

[11] defines the main features of DT as follows:

1. Connectivity- A connection is required between the DT and its real-life equivalent that ensures a continuous and reliable data flow.

2. Homogeneity - the data from different sources should be homogenized.

3. Reprogrammable- as the volume of regularly collected data increases, DT also develops and provides smarter decision-making through artificial intelligence.

4. Modularity- DT can allow the manufacturer to learn which specific components of the device are underperforming.

A connection between the DT and its real-life equivalent that ensures a continuous and reliable data flow is a prerequisite. Thus, DT is updated and changes as its physical equivalent changes. It uses IoT to understand the physical object's current state, location, function, composition, etc. The generated unstructured data is then transmitted to the virtual twin in real time, resulting in a dynamic representation of the situation. DT can learn from this data through machine learning, from human experts with deep knowledge in the subject field, as well as from identical twins [12].

Thus, the general architecture of the medical DT consists of physical and virtual objects, technologies that ensure the connection between them, a unified health database, a centralized management system and visualization systems (Figure 1) [13].

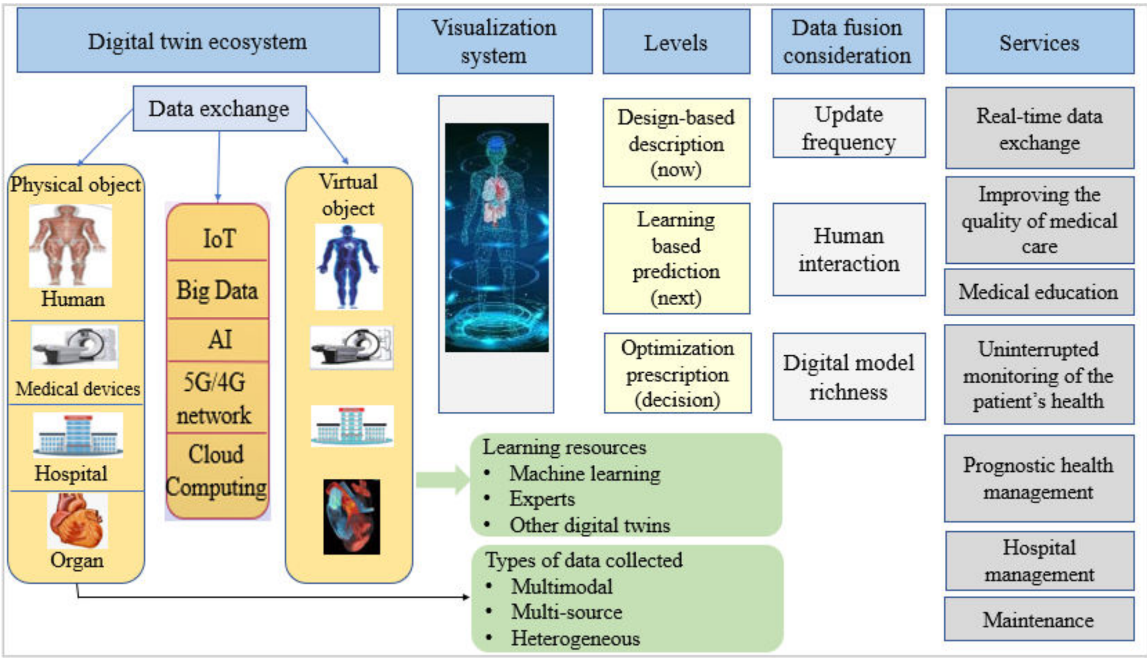

Figure 1: *Generalized architecture of medical digital twins [13]*

The **physical objects** of a medical digital twin refer to patient, hospital, doctor, medical devices, organs, etc.

Table 1 presents the information required for building the DT of the physical objects of the health care system.

Table 1: *Information required for building the DT*

№	Physical objects of healthcare system	Information required for building the DT
1	Patient	Genetic data, laboratory results, medical images, biomedical signals, personal data, social determinants
2	Hospital	Medical resources (equipment, medicinal preparations, etc.), personnel resources, intra-hospital operational data, building layout
3	Health data collectors	Sensor data, quality indicators, environmental data

Along with all examination data of the relevant physical object, data regularly collected through 4G/5G, IoT, IoMT are used to form a database of personalized medical DT [14,15]. The data collected from physical objects are large-scaled and diverse in nature, but also obtained from different sources, and in this regard, they can be classified as follows [16]:

• IoT devices: Blood pressure, heart rate and other biometric parameters;

• Electronic Health Records (EHR): Laboratory results, treatment plans and health regords;

• Artificial intelligence and analytical models: Data for patient health predictions and early disease detection, etc.

This data is stored in databases such as cloud systems or SQL servers.

A **virtual object** is software consisting of a set of applications that explain the behavior of a medical object on a computer. Applications are used as a real-time control system of the object's activity, and this system operates throughout the entire life cycle of the object.

Visualization system displays data management models, information from various sources and results in a visual form in different fields of medicine. This enables effective monitoring, control and management of processes occurring in a medical physical facility.

III. Problem statement

I. Establishment of the DG at the level of the human body organs and relevant diseases;

II. Creating a digital twin through health data visualization.

IV. Problem solution

I. The study proposes the implementation of the following stages of the DT at the level of the human body organs and relevant diseases:

1. *first stage* is characterized by the collection of necessary medical data on each relevant physiological level. This stage builds a general (standard) digital model of the physical medical object based on available medical data;

2. *second stage* performs collection, integration and analysis of data about a specific individual, and creates an individual model of a physical object through modeling;

3. *third stage* analyzes the differences between the general and individual model built:

a) deviations in the considered parameters according to all physiological levels are determined;

b) an intellectual analysis of the current situation is performed and an appropriate decision is made;

c) obtained positive decisions are used for examination, diagnosis, prediction of diseases and prescription of the therapy of the patient.

Figure 2 presents a schematic illustration of the proposed functionalization of the DT based on medical data regularly collected from patients.

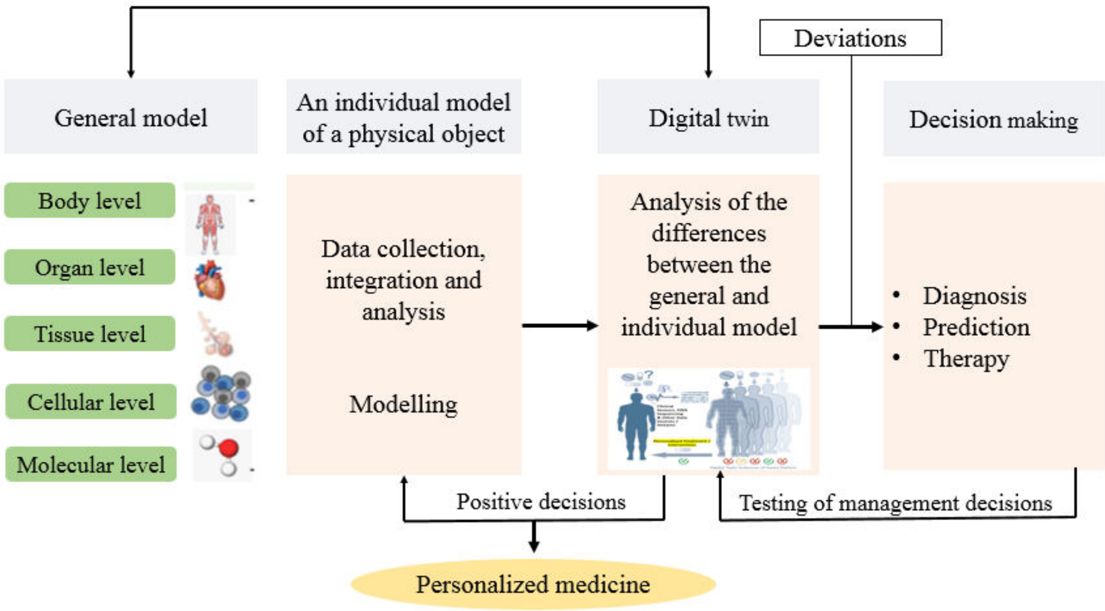

Figure 2: *Formation of DT based on medical data collected from patients*

II. Visualization of a digital twin is a visual representation of a virtual object based on continuously collected data to update it simultaneously with the changes occurring in the physical object [17]. This article uses Power BI software, a cloud-based data analytics platform developed by Microsoft, to visualize real health data. Power BI collects and cleans data from external sources, creating data models, analyzing and visualizing data. As the visualization tool, Power BI has a more user-friendly interface than others. Power BI enables intuitive visualization and continuous updating of digital twin data by linking the built-in dashboard with data collected from a real physical object. Visualization of medical digital twin data through Power BI is a viable approach to optimize healthcare services and improve decision-making based on real-time data [18].

The algorithm for creating a digital twin with the visualization of health data based on Power BI is performed in the following stages:

Stage 1: Selection of the base. In this regard, data can be connected to Power BI from sources such as Azure Data Lake, SQL Database, APIs or Excel.

The present study refers to existing national database, which is periodically collected by doctors in traditional clinical practice regarding patients, as a real source of information. The real database is a database of cirrhosis patients created in Excel by doctors of the Surgical Diseases Clinic of Azerbaijan Medical University (Figure 3).

Name	Gender	Date	Diagnosis	Age	İnterval	Birth date	BWI	MELD	HB	Leuk
Patient 14		11/2/2022	Cirrhosis			1960		9	14.5	5.54
Patient 14		6/23/2023	Cirrhosis			1960		8	13.1	5.27
Patient 14		11/15/2023	Cirrhosis			1960		10	13	5.02
Patient 15	Female	10/12/2019	HBV, Cirrhosis	52	50-60	1972			13.4	8.44
Patient 15		11/4/2022	HBV, Cirrhosis						13.3	7.44
Patient 15		4/5/2023	HBV, Cirrhosis					9	13.5	7.53
Patient 15		4/27/2023	HBV, Cirrhosis					12	13.4	6.64
Patient 15		7/24/2023	HBV, Cirrhosis					12	12.9	6.72
Patient 15		11/1/2023	HBV, Cirrhosis					8	12	5.96
Patient 16	Male	5/10/2023	Alk, Cirrhosis	53	50-60	1971		12	11.4	4.25
Patient 16		6/12/2023	Alk, Cirrhosis			1971		12	11	3.65
Patient 16		10/27/2023	Alk, Cirrhosis			1971		12	11	3.47
Patient 17	Female	4/30/2021	Cirrhosis	67	60-70	1957			13.7	5.72
Patient 17		6/29/2021	Cirrhosis			1957		10	11.2	5.6
Patient 17		10/4/2021	Cirrhosis			1957		10	11.6	4.51
Patient 17		7/13/2022	Cirrhosis			1957		12	11.8	4.66
Patient 17		6/19/2023	Cirrhosis			1957		15	11	4.48
Patient 17		8/2/2023	Cirrhosis			1957			11.3	3.93
Patient 18	Male	7/31/2023	Alk, Cirrhosis	59	50-60	1965			13	3.74
Patient 18		8/15/2023	Alk, Cirrhosis						11	2.95
Patient 18		9/15/2023	Alk, Cirrhosis					15	13	3.02

Figure 3: *Fragment from the database created by the doctors of the Surgical Diseases Clinic of Azerbaijan Medical University on cirrhosis diseases*

Stage 2: Uploading the data collected in the Excel database to the visualization program.

Stage 3: Data transformation is performed. Data transformation in Power BI is implemented through Power Query. At this stage, the following main tasks are executed:

• If empty cells are found in the medical records, they are either deleted or filled in accordingly;
• Detection of outliers, i.e., examination of abnormal values;
• Generated unstructured data is structured and so on.

Structuring the data from a physical object provides the following opportunities:

• Analyzing patient data more accurately;
• Detecting risky situations in advance;
• Making decisions based on real-time (live) indicators.

By the implementation of the listed stages of transformation, it is possible to create visual images for each medical parameter characterizing the patient's condition.

Stage 4: Building a digital twin dashboard. Data visualization enables healthcare professionals to monitor patient conditions in real time and make flexible decisions. Dashboards in Power BI provide detailed analysis and targeted monitoring.

Fig. 4 shows the control panel of the digital twin based on dynamic examination data of cirrhosis patients: a) by the cirrhosis types (HCV cirrhosis, HBV cirrhosis, ALK cirrhosis, cirrhosis); b) by the demographic distribution of patients (age, gender).

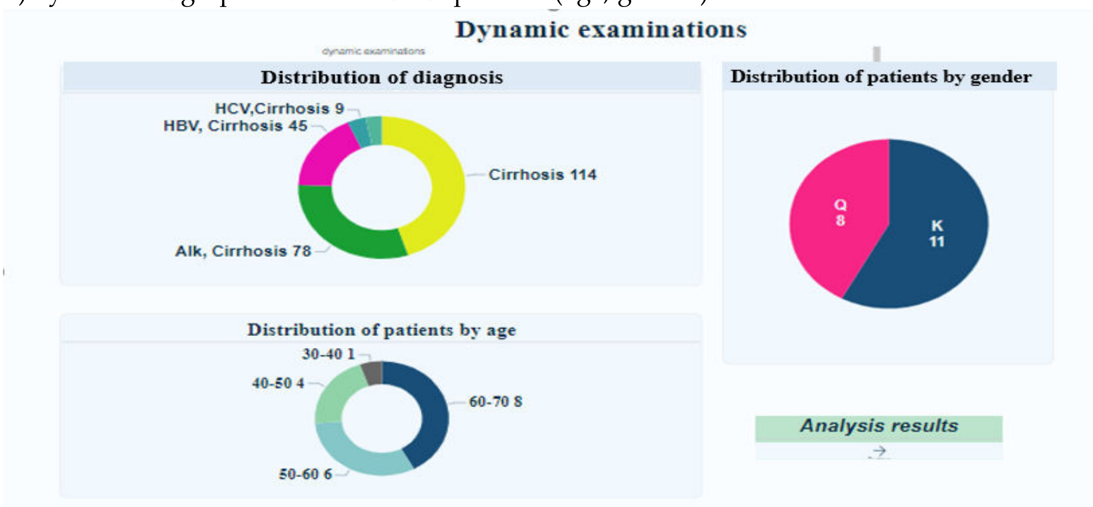

Figure 4: *Digital twin control panel: a) by the cirrhosis types (HCV cirrhosis, HBV cirrhosis, ALK* cirrhosis, cirrhosis); b) by the demographic distribution of patients (age, gender)

As shown in the figure, 11 patients are male, 8 are female, 1 patient is aged 30-40, 4 patients aged 40-50, 6 patients aged 50-60 and 8 patients aged 60-70.

When we click on the "Analysis results" button, the window illustrated in Figure 5 opens.

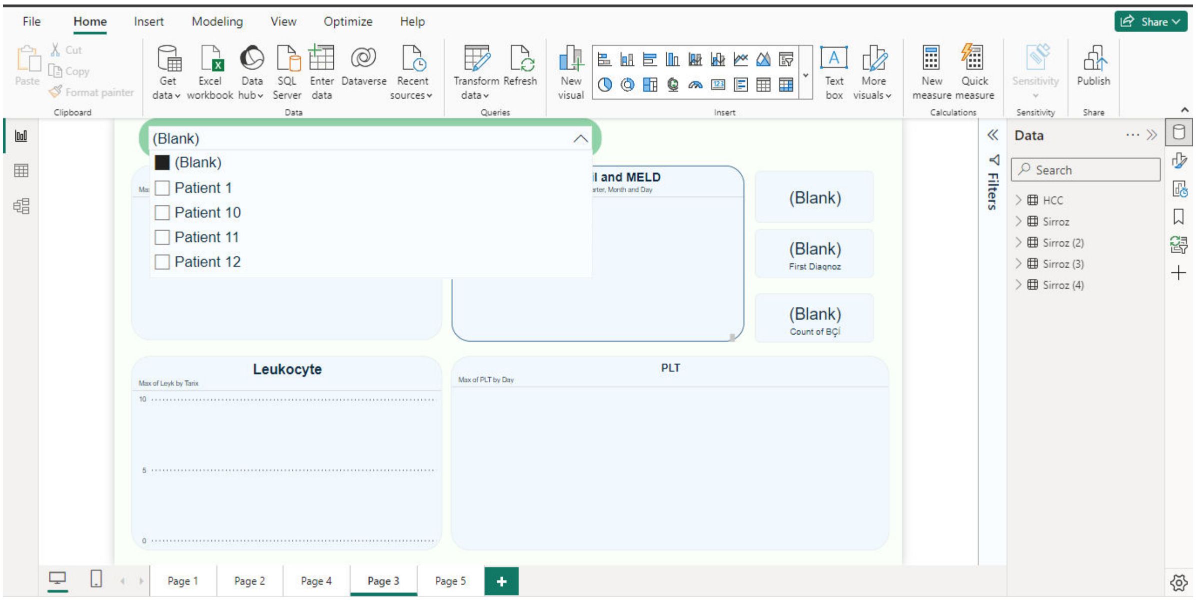

Figure 5: *"Analysis results" login window*

To view individual analysis results of any patient in the login window, select the patient's name from the list. In the window depicted in Figure 6, it is possible to see the patient's year of birth, type of disease, and how laboratory analysis results change over time through visual tools, such as Gauge chart, line chart, and slicer for a specific selected patient. By approaching any point in those graphs, it is possible to see the date and result of the analysis.

Figure 6: *Visual image of a digital twin of a cirrhotic patient*

Real-time visualization of data from a physical object through dashboards created in Power BI provides the following opportunities:

• The dashboards represents the dynamics of time series formed on each medical parameter of the patient;

• Early prediction of diseases and optimization of treatment processes are ensured;

• Decision-making process accelerates for physicians by creating a visual representation of personalized indicators related to each patient.

Such a "digital twin" contains information about the patient, shows trends in the development of the disease, and shapes the patient's health trajectory by updating the data after each medical examination.

Based on our proposed algorithm, it is possible to create a digital twin by visualizing examination data related to other diseases in a similar manner.

Thus, the visualization of personal health data through Power BI allows for continuous monitoring of patients' conditions and timely medical interventions through dashboards created in real time.

V. Summary

The use of medical digital twins has great potential for improving individual treatment programs in the healthcare sector. This article presented the architecture of creating a DT - the transformation of a physical object into a virtual object based on data collected from patients. It proposed the architectural and technological principles of DT at the level of the human body organs and relevant diseases and the stages of virtual object formation and a schematic description. When creating a DT, data collected regularly under the supervision of doctors in clinical practice were referred to as real-time data, and an algorithm for building a visualization system on the Power BI platform was given. The Power BI visualization tool visually depicted the trajectory of change of that parameter according to parameters recorded at different points in time, creating the conditions for viewing the patient's vital medical indicators in context with time and space components, which supported doctors in assessing the criticality of the current situation. In further studies, it is planned to conduct research on the prediction of the patient's health based on clinical data through the integration of Power BI with artificial intelligence models.

References

[1].J.Reis, M. Amorim Melão, P. Matos, Digital transformation: a literature review and guidelines for future research, World Conference on Information Systems and Technologies, (2018) 411–421.

[2]. K. Zhang, H. Zhou, T. D. Baptista-Hon, etc. Concepts and applications of digital twins in healthcare and medicine, Patterns, 5, (2024), https://doi.org/10.1016/j.patter.2024.101028.

[3]. K. Y. H. Lim, P. Zheng, C. H. A. Chen, State-of-the-art survey of digital twin: Techniques, engineering product lifecycle management and business innovation perspectives, Journal of Intelligent Manufacturing, 31, (2020) 1313–1337. DOI: 10.1007/s10845-019-01512-w.

[4]. M. Grieves, J. Vickers, Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems, Transdisciplinary Perspectives on Complex Systems, (2017) 85–113.

[5]. M. Grieves, Digital twin: Manufacturing excellence through virtual factory replication, 2014, pp. 8 .

[6]. L. El-Warrak , C.M. Farias. The State of the Art of Digital Twins in Health—A Quick Review of the Literature, Computers, 13 (2024) 9 https://doi.org/10.3390/computers13090228.

[7]. G. Coorey, G.A. Figtree, D.F. Fletcher, et al. The health digital twin to tackle cardiovascular

disease—a review of an emerging interdisciplinary field, Digit. Med. 126 (2022) 5, https://doi.org/10.1038/s41746-022-00640-7.

[8]. A. Ahmadova, Applications of digital twins in medicine and the ontological model of medical digital twins, Problems of Information Society, 15, (2024) 98-105, http://doi.org/10.25045/jpis.v15.i1.10.

[9].T. Sun, X. He, X, Z. Li, Digital twin in healthcare: Recent updates and challenges, Digit Health, 9 (2023) 1–13, doi:10.1177/20552076221149651.

[10].D. Silva, M. Azevedo, A. L. Soares, A Vision for a Platform-based Digital-Twin Ecosystem, IFAC-PapersOnLine, 54, (2021) 761-766, https://doi.org/10.1016/j.ifacol.2021.08.088 .

[11].B. Barricelli, E. Casiraghi, D. Fogli, A Survey on Digital Twin: Definitions, Characteristics, Applications, and Design Implications, IEEE Access, 7 (2019) 167653-167671, doi: 10.1109/ACCESS.2019.2953499 .

[12].R. Liyanage, N. Tripathi, Päivärinta, Digital Twin Ecosystems: Potential Stakeholders and Their Requirements. In: Carroll, N., Nguyen-Duc, A., Wang, X., Stray, V. (eds) Software Business. ICSOB 2022. Lecture Notes in Business Information Processing, 463. (2022) https://doi.org/10.1007/978-3-031-20706-8_2.

[13].M. Mammadova, A. Ahmadova, Development of digital twin ecosystem and ontology in medicine. Technology transfer: fundamental principles and innovative technical solutions (2023) 21–23. doi: https://doi.org/10.21303/2585-6847.2023.003203

[14].M. Mammadova, Z. Jabrayilova, Synthesis of decision making in a distributed intelligent personnel health management system on offshore oil platform. EUREKA: Physics and Engineering, 4 (2022) 179–192. https://doi.org/10.21303/2461-4262.2022.002520.

[15].M. Mammadova, Z. Jabrayilova, Decision Making in a Distributed Intelligent Personnel Health Management System on Offshore Oil Platform. Studies in Fuzziness and Soft Computing. 423 (2023) 145–153.

[16].O.S. Kobyakova, V.I. Starodubov, N.G. Kurakova, L.A. Tsvetkova, Digital Twins in Healthcare: Assessment of Technological and Practical Prospects, Annals of the Russian Academy of Medical Sciences, 76 (2021) 476–487.

[17].Y. Fan, J. Yang, J. Chen, X Wang, B. Zhou, A digital-twin visualized architecture for Flexible Manufacturing System, Journal of Manufacturing Systems, 60 (2021) 176-201, https://doi.org/10.1016/j.jmsy.2021.05.010Get rights and content.

[18].S. M. Zulkafli, M. M. Ariffin, A. Zakariya, Data Analytics and Visualization of Remote Healthcare Monitoring System, 6th International Conference On Computing, Communication, Control And Automation (ICCUBEA, 2022, 1-6, doi: 10.1109/ICCUBEA54992.2022.10010938.