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DEVELOPMENT OF A PATIENT HEALTH MONITORING SYSTEM BASED ON A SERVICE-ORIENTED ARCHITECTURE USING ARTIFICIAL INTELLIGENCE

The object of the study is a patient health monitoring system that uses service-oriented architecture (SOA) and artificial intelligence (AI) to integrate and analyze medical data. Such a system integrates data from a variety of sources, including medical devices, health apps, electronic health records, and wearables and physiological performance recorders, providing a comprehensive approach to health monitoring. Thanks to SOA, the system is able to process large arrays of data in real time, providing the opportunity to quickly process and analyze them. This allows medical professionals to get a comprehensive picture of patients' health, taking into account both long-term trends and real-time indicators.

One of the most challenging areas is ensuring effective integration and processing of disparate data from various medical devices and applications for accurate diagnosis and prognosis of diseases. It is also important to create a system that is easily scalable and can be adapted to the needs of different medical facilities and various monitoring systems.

As a result of the research, it is concluded that the use of SOA allows creating flexible and scalable systems capable of integrating a wide range of medical devices and applications. The use of AI in these systems makes it possible to automatically detect deviations in health indicators, recognize pathologies in the early stages and predict the possible development of diseases. This is due to the fact that the proposed architecture has a number of features, in particular, the ability to collect, process and analyze large volumes of medical data in real time. Artificial intelligence algorithms provide high accuracy of diagnosis and forecasting thanks to the ability to quickly process complex data and find hidden patterns. Thanks to this, it is possible to obtain accurate and reliable indicators of the state of health of patients. Compared to similar known systems, it provides such advantages as increased efficiency of medical care, reduced risk of complications, early detection of diseases and a personalized approach to patient treatment, as well as the concentration of all data in one system.

Keywords: *SOA, medical data processing, AI, edge computing, microservice architecture, data classification, medical Internet of Things.*

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1. Introduction

The rapid growth of the Internet of Things [1] and the daily use of the Internet make it possible to wear a large number of sensors in everyday life. At the same time, sensors can be used for many things – from monitoring the quality of the air a person breathes, to the number of steps per day or blood sugar level [2].

In the conditions of population growth and the spread of various diseases, health care systems are moving to the use of telemedicine [3], which uses sensors to monitor physiological parameters and the environment, helping to ensure further contact with the patient, which reduces the probability of the spread of diseases. Parameters measured by physiological sensors can be: heart rate, breathing rate, oxygen saturation (SpO_2), body temperature, blood sugar level, etc. «Environmental sensors» can measure parameters related to light intensity, the location of the patient in the house, etc. The physiological sensor network is called a body area sensor network (BASN); in this network, a group of wearable sensors is deployed on the human body. In general, sensor networking has several limitations, such as data aggregation, security, heterogeneity of sensor networks, energy consumption, etc. [4, 5]. Another important aspect of sensor networks is that it is important to maintain semantic interoperability, that is, to unify the meaning of data at all levels of the network architecture. Semantic interoperability in healthcare solutions based on service-oriented architecture allows to standardize and be able to change only the necessary services, without affecting the entire system.

Remote patient monitoring systems that monitor patient status and record all data can use service-oriented architecture (SOA) to create converged, distributed, and scalable architectures. Web-based control systems are used to provide integration and interaction between a distributed sensor network and the wireless Internet [6]. The functionality of the service-oriented architecture consists in the access of one or more interfaces through the master program. These interfaces define different methods available over the network and are called «services» [7].

The aim of the research is to develop and improve methods of integration and analysis of disparate data from wearable sensors, using service-oriented architecture and artificial intelligence algorithms, for accurate monitoring of physiological parameters and the environment of patients. This includes identifying regularities in the interaction of physiological and environmental parameters, developing a model for effective aggregation and analysis of data from various sources, as well as determining mechanisms for ensuring semantic compatibility in telemedicine systems. This will make it possible to create flexible and scalable remote patient monitoring systems that will provide high-precision monitoring of health in real time, promote early detection of pathologies, increase the efficiency of medical intervention, reduce the risk of complications and improve the overall quality of medical services. The proposed methods will allow optimizing the use of sensors in everyday life, increasing their energy efficiency and safety, which, in turn, will contribute to a wider implementation of telemedicine technologies in healthcare systems.

2. Materials and Methods

2.1. Service Oriented Architecture: SOA. The functionality of the service-oriented architecture model is that it exposes one or more interfaces through a specific application. These interfaces define various methods that are available over the network and are called «services» [7, 8]. Those who use these services are called service consumers, and those who provide them are called service providers. Each of these services is independent and includes business logic and data related to this particular service. They can be interconnected, thereby improving the potential of the architecture. To do this, architectures must use a set of rules or protocols to define the message format. These protocols define the data exchange policy. SOA is a term representing a model in which logic is broken down into distinct and small units. These units can be distributed, and together they form part of the automated business logic. A significant advantage in SOA implementation is flexibility in responding to changes in business requirements [9]. Interoperability and ease of maintenance become an advantage when SOA is properly implemented, however, if we want to implement an architecture based on SOA, it is possible to take into account the preservation of its main goals: the infrastructure must support flexibility, heterogeneity, distributed development and management [9, 10].

According to [11], the structure of the SOA architecture can be considered as a seven-level architecture:

1. *Operational system layer*: This layer integrates existing systems using SOA-based integration techniques.
2. *Corporate component layer* is responsible for implementing the functionality and ensuring the quality of service (QoS) of the provided services.
3. *Service layer*: at this level are the services that are selected for use.
4. *Business process layer*, which defines the services presented in layer 3.
5. *Access layer*: It is designed to provide comprehensive solutions for service compositions.
6. *Integration layer*: it allows the integration of different services.
7. *Management and security*: It is responsible for monitoring, managing and ensuring security.

2.2. Security in SOA applications. Security is one of the most important issues in wireless sensor networks. The use of online services may expose eHealth to the same risks as any other online application. The identity of a legitimate eHealth user should be carefully verified before granting access privileges [12].

SOA increases the number of access points for enterprise systems, also increasing the vulnerability of the site, since many of these points have Internet connections [13, 14]. Enterprise-level security has evolved with technological advances and has always sought to maintain a «wall» between what needs to be protected and those who have access to it, in order to prevent access by attackers or unauthorized personnel.

Not only must the architecture be protected from those accessing the system via the Internet, but it must also be protected from those accessing the intranet, because internal networks can be accessed from insecure physical points within the organization [13]. Progress in implementing SOA is directly proportional to the security risks that this architecture creates.

To build healthcare services, it makes sense to use both proprietary vendors such as Azure or AWS, as well as solutions based on private clouds, taking into account data security [15]. The main components used to build such systems are available both from vendors and in an open form for use in a private cloud:

– *Kubernetes* is an open service orchestration system for flexible distribution of resources between them [16].
– *Persistent Volumes (PV) and Persistent Volume Claims (PVC)*: PV and PVC in Kubernetes enable storage management at the cluster level, similar to how S3 provides cloud storage. PVs are responsible for provisioning physical storage, while PVCs allow users to request specific storage resources.
– *Services*: Services in Kubernetes allow to interact with pods and route network traffic. They play a similar role to load balancers in EC2, providing a constant access point to pods [17].
– *Pods*: These are the smallest and simplest units in Kubernetes that it is possible to create or deploy. A pod is similar to the concept of virtual servers in EC2, but at the containerization level, where each pod can contain one or more containers.
– *ConfigMaps and Secrets*: These components allow to store configuration data and secrets, respectively, that can be used by pods. They are similar to storing configuration files and sensitive data in S3 or RDS.

2.3. eHealth as part of the Internet of Things (IoT). IoT is an ever-growing ecosystem that combines hardware and software [18]. These components come together through the devices that humans or animals use, allowing them to interact, communicate, collect and share data. This provides various advantages for creating human (patient) centered services. A fundamental aspect in the application of this new service model is to obtain data that, after analysis, allows a series of decisions to be made, as well as to obtain a series of observations and evaluations for further analysis. To understand how data is generated and managed, a multi-level architecture divided into four different levels can be considered [18]. The first layer is the perception layer, which is responsible for connecting to the real world and collecting data. The second layer is the network layer, which provides network support and data transfer in networks (wired and wireless). The service layer creates and manages all services aimed at satisfying user requirements. The final layer is the interface layer, which provides interaction methods for users and other applications.

Typically, each of the mentioned layers can be identified by specific resources (hardware and/or software) located in specific locations. In the case of eHealth, the sensor layer should mainly be identified with the family of specific sensors and electronic platforms used by patients/users to collect health data. The network layer, and probably a part of the service layer, should be identified with some communication device or computing resource having computing and communication capabilities. The top component of this level can be the main server or cloud computing resource, where the results of data collection and their calculations will be protected and stored. Finally, the interface layer, which provides an easy and practical interface for the user (presumably, the patient interface is performed at the smartphone or tablet application level, and the professional interface should be provided at the web level, with a connection to a cloud service).

Thus, the service layer provides the actual medical services, such as processing patients' health data related to their condition (e. g., blood pressure and glucose levels). The interface layer provides various types of software that allow users of the system to receive output data. In turn, these interfaces provide an opportunity to analyze and read data in a convenient format for both doctors and patients.

2.4. Use of artificial intelligence in eHealth. The main challenge that arises in eHealth and its combination with IoT systems is the correct processing, interpretation and use of data about the patient or user and their condition, which is generated by the new human-centered service model. In the near future, the large volume of information generated and accumulated will require healthcare organizations to quickly adapt to new technologies and their development.

The main goal of AI-powered eHealth is for the healthcare system to be strengthened by a series of strategies based on extracting the knowledge accumulated in the large amount of data that the system generates about patients.

The data collected by certain portable devices can be conveniently processed for sending and integration to a higher level, in the patient's medical history (Electronic Medical Record EHR) existing in the server system or the computing cloud of the hospital. Other available information at this level of the architecture is a set of data related to the e-prescription, which allows professionals to have privileged information and knowledge about the patient's condition and development.

The methods used in artificial intelligence are aimed at integrating knowledge about a problem (in our case – health care) into an algorithmic set with the goal that, after the learning process, the AI system can generalize solutions to cases that it has never analyzed before. This knowledge is based on the analysis of relevant data and is accumulated in the learning process. Among the advantages of using artificial intelligence methods for electronic health care, the following can be mentioned:

– *Personalized medicine*. The challenge of personalized medicine is a scenario in which health or treatment recommendations for a given patient are based on a patient's specific medical history, genetic inheritance, past illnesses, diet, stress levels, etc. It is quite obvious that the contribution of eHealth in combination with embedded AI methods, which allows intelligent processing of this information, is possible.

– *Access to recommendations and automated treatment*. For certain pathologies (for example, diabetes), where the diagnosis is already established and the treatment is clearly defined, a step can be taken to better manage the prescribed treatment based on the analysis of the eHealth application with built-in artificial intelligence. Data analysis can generate a set of automatic or semi-automatic actions that affect treatment. In this case, additional aspects appear (ethical and safety aspects).

Other general aspects related to combining eHealth with the IoT environment [19]:

– *Sensor interaction*: several sensors with different functions coexisting in the system.

– *Lifelogging mode*: constant monitoring and access to personal data throughout life.

– *Uncontrolled environment*: The new emerging scenario is the uncontrolled transformation of traditional healthcare services with a large population of elderly people.

– *Large amount of data*.

– *Data security and privacy*.

3. Results and Discussion

3.1. Patient monitoring. AI can be used to continuously monitor the condition of patients and detect changes that may indicate deterioration of health or the risk of developing complications. The use of artificial intelligence (AI) in monitoring can help detect problems early and provide recommendations for further treatment.

The application of AI using wearable sensors is an integral part of the Internet of Things (IoT) revolution. As a result of the rapid development of artificial intelligence methods, healthcare professionals have gained a greater opportunity to work with huge amounts of data that are collected using wearable devices to monitor the health of patients. Artificial intelligence improves the ability to explore the relationships between information obtained from sensor signals and people's health by establishing different types of diagnostic and predictive models. The use of artificial intelligence in the processing of data from wearable sensors is extremely important for optimizing the diagnosis and prediction of cardiovascular diseases.

Fig. 1 presents a visualization of the above system.

Such a system consists of the following groups of components [21]:

1. *Mist computing layer* – body sensors attached to the patient's clothes and (or) body.

2. *Fog computing layer* – a system consisting of a controller and a communication module that supports the Bluetooth Low Energy (BLE) standard, and batteries to support their operation.

3. *Edge computing layer* – a smartphone with BLE communication support with an installed application. The developed application allows integration of the end and cloud levels, provides feedback to the client. This level also includes the two above. Thanks to modern energy-efficient systems-on-a-chip and optimized deep learning models, it is already possible to recognize exacerbations of the user's condition at this level.

4. *Cloud computing level* – a cloud application that is responsible for saving and providing access to collected patient data, their detailed analysis using artificial intelligence methods and consists of:

– data storage and access service (both normalized and denormalized);

– data analysis service;

– authentication and authorization service for client applications.

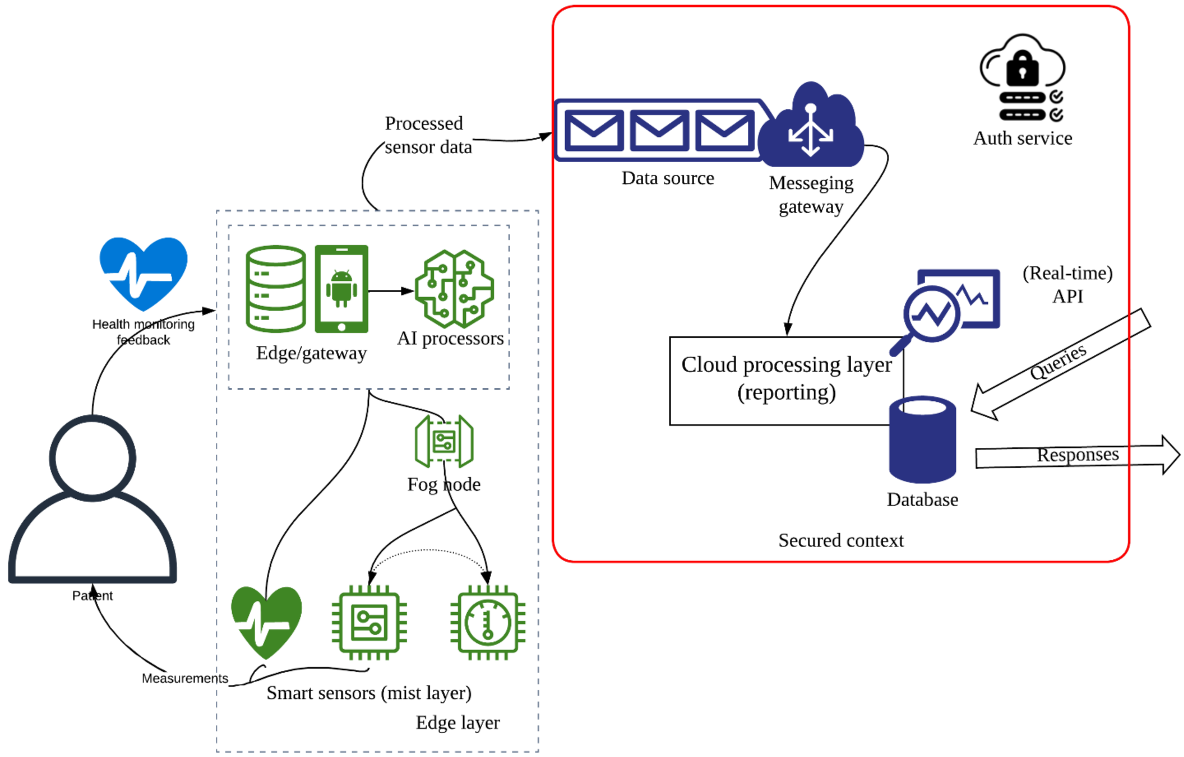

Fig. 1. Architecture of the system of continuous monitoring of the patient's condition [20]

Approaches based on artificial intelligence and machine learning are outperforming traditional statistical methods in disease prediction. However, due to the lack of real-world data to assess the quality of disease analysis, additional studies on real patients are needed. This is necessary in order to collect a larger database for their analytics and analysis, as well as to evaluate the performance of wearable devices and the security of the system.

The integration of artificial intelligence and SOA architecture has raised security and privacy concerns, especially in the healthcare industry where sensitive patient data is used.

To protect confidential information and avoid cloud storage of deanonymized data, it is proposed to break the architecture into loosely connected levels with high coherence within each level. This approach involves partial processing of private data at the edge of the infrastructure and transfer of only aggregated and anonymized data to the cloud system. The architecture of the system is built from the following levels, as shown in Fig. 2.

The expert level is defined as a doctor recorded by the patient, capable of prescribing treatment and approving analytical level recommendations.

The cloud layer is responsible for collecting, storing, analyzing and integrating data with external sources. Although it is scalable, cost-effective, and provides easy access to information, it is highly vulnerable to various types of attacks, from denial-of-service (DDOS) attacks to targeted system attacks.

The private client layer consists of the BSN fog computing layer, the cloud gateway, and the user interface (UI) layer. These sublayers are responsible for processing sensor output data, obtaining context, integrating with the cloud, and providing feedback to the patient [23].

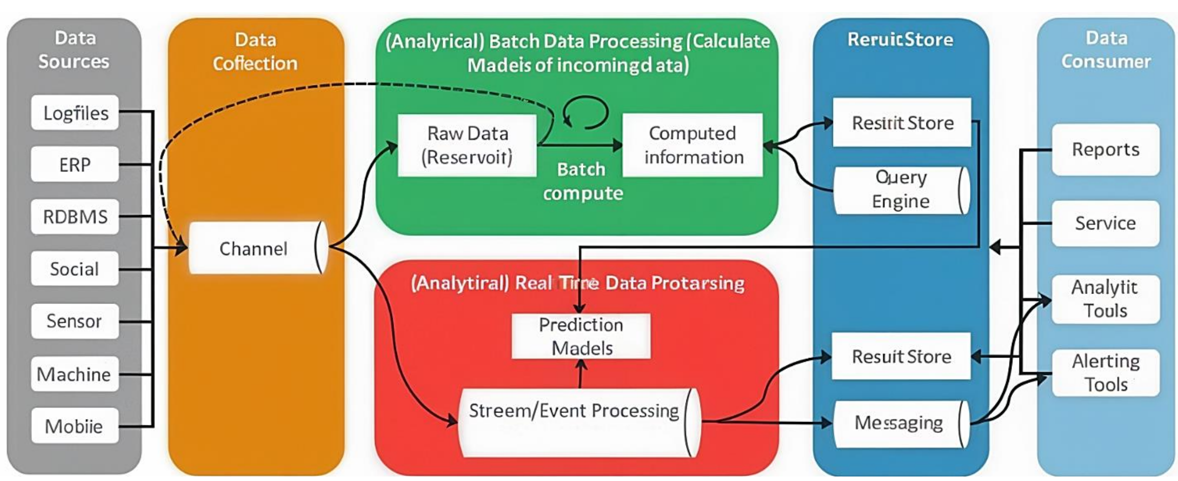

Fig. 2. Proposed system levels and groups of services [22]

A user's smartphone is typically used as a cloud gateway, as it provides cloud-level Internet connectivity and Bluetooth to communicate with sensor networks, combined with sufficient computing power to process data and always-know user location data and other contextual data. Basic data collection and processing is performed on smart sensors, which reduces network load and solves security and privacy issues. Moreover, modern smartphones can even participate in the process of data analysis.

In this way, it is possible to obtain a modified lambda architecture (Fig. 3).

This approach differs from the traditional lambda architecture in the following stages [20, 21]:

1. The component of rapid data analysis is transferred from the cloud to the end layer of the network. At the same time, the processing results continue to be sent to the cloud for permanent storage. This approach reduces network latency and optimizes the amount of data transferred to the cloud. It also reduces the security requirements for databases, because now only the processing results are stored, the leakage of which is safer from the point of view of protecting the privacy of the user. In addition, the approach reduces the availability requirements of the cloud component of the system, allowing it to be deployed on spot servers with reduced dynamic cost, which can help avoid redundant infrastructure and reduce node fault tolerance requirements.

2. The data is transmitted in a reformulated form, so the need for a dedicated data lake disappears and the load on the batch analysis component is significantly reduced. As medical systems are constantly changing and new machines and equipment are created, as well as treatment protocols and disease staging, it is important to be sure that these changes can be easily and quickly integrated into the existing system without affecting it in general. This task is well handled by microservices, and data protection and system fault tolerance are created with the help of service orchestration and load balancers. The AWS platform provides such opportunities, as well as the ability to create functions and execute them only when it is really needed, saving financial costs and reducing the load on all other processes in the system.

3.2. Assessment of research results. During the research and development of the system architecture, most of the known health monitoring systems were worked out. Most of them have a well-designed architecture, but have difficulties with expansion and the use of third-party services or devices. The performed research makes it possible to build a medical system that is easy to expand and adapt to the requirements of the end user. This system is flexible to a variety of systems and does not require complex integration processes for new sensors or wearable devices. However, due to the lack of quality data and the availability of testing devices on real patients, there have been challenges in creating a high-load and safe system. Also, the main problem was the use of non-certified sensors, which can cause a conflict of interests and the danger of limiting the scope of use of this system.

Due to the flexibility and unification of the service-oriented architecture, this system can be used even in a state of war and create unique services that can be adapted and used for military tasks. It is also possible to connect various systems via Bluetooth/cable connections, which provides a wide range of system usage.

3.3. Challenges and prospects. The new era in healthcare also creates concerns about data sharing. Some experts agree that infrastructure, regulations and usage policies that facilitate data sharing are needed to maximize its benefits, while others worry about cyberattacks and patient privacy. Therefore, it remains to be decided how to benefit from public data sharing, ensuring the safety and confidentiality of patient information [24].

4. Conclusions

The study shows that the integration of artificial intelligence (AI) and service-oriented architecture (SOA) in healthcare systems shows significant potential for improving healthcare services. The results show that using AI together with SOA provides improved diagnostic accuracy, real-time monitoring, development of personalized treatment plans, and proactive patient health management.

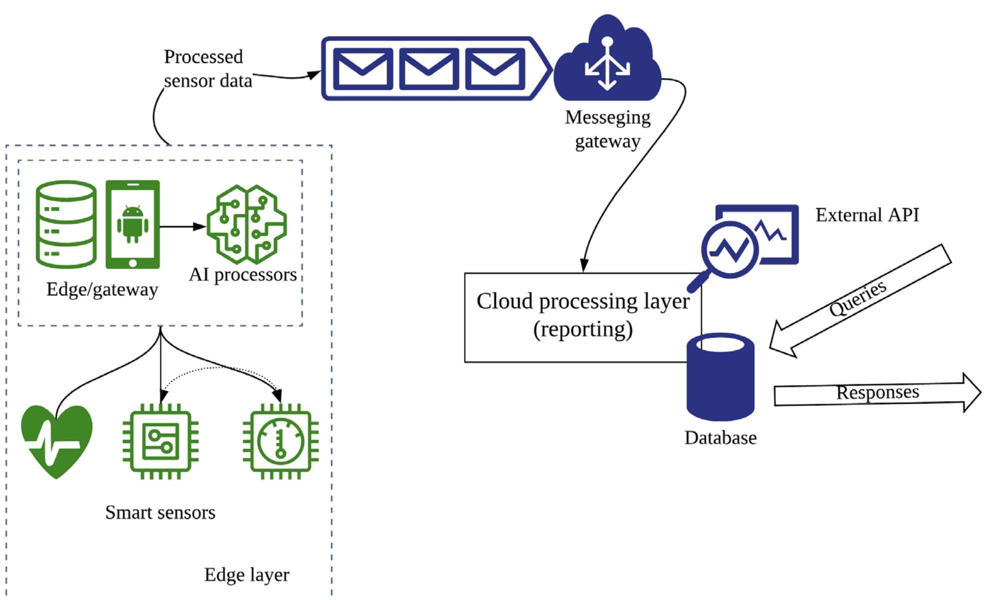

Fig. 3. λ-architecture using finite computations

These results are explained by the ability of AI to process and analyze large volumes of medical data, to identify patterns and anomalies, which contributes to accurate diagnosis and prognosis of diseases. SOA provides flexibility and scalability of the system, which allows the integration of various medical devices and applications, increasing the efficiency and availability of medical services.

The practical benefit of these results lies in increasing the efficiency of medical care, reducing the risk of complications due to early detection of pathologies, optimizing the use of medical resources, and improving the quality of patient treatment. Theoretically, the results emphasize the importance of integrating the latest technologies into medical practice, which contributes to the development of innovative methods of treatment and monitoring.

However, it is important to note that the integration of AI and SOA has a number of challenges. Data standardization, interoperability, algorithm transparency, and ethical aspects must be carefully considered by various stakeholders: medical professionals, lawyers, and information system architects. Cooperation between these groups, adherence to established norms, and continuous technological progress are key to the successful integration of artificial intelligence and SOA [25].

In summary, the combination of AI and SOA has significant potential to change the healthcare delivery paradigm. The use of microservices in the field of health care can contribute to the discovery of new possibilities of the medical Internet of Things, which will lead to improved results of patient treatment, optimization of the use of resources, and improvement of the quality of medical practice. The integration of AI and SOA paves the way for a more streamlined, productive and patient-centric healthcare ecosystem.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, including financial, personal, authorship, or any other nature that could affect the research and its results presented in this article.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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