

Smart Hospital medical equipment: integration into the enterprise architecture

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Abstract. Digitalization is actively affecting various areas of our lives and healthcare is no exception. The concepts of e-health, Smart Hospital and the principles of value-based and personalized medicine are increasingly becoming the object of research and approbation in organizations around the world. This article will consider the opportunities for medical organizations that follow the trends in the modern digital technologies development. Moreover, Smart Infrastructure will be presented as part of a comprehensive architectural Smart Hospital solution.

Keywords: Smart Hospital, enterprise architecture, e-health, medical equipment, infrastructure, digital technologies.

1 Introduction

Every year the level of computerization and digitalization of various industries increases, the idea of digital transformation covers the whole world. This leads to the fact that most developed countries, including Russia, pay great attention to such terms as digitalization and digital transformation for in-depth study of a new field of scientific and technological progress.

Currently, the number of new technologies and their capabilities is growing exponentially. In the course of a new technological revolution that has affected various business areas, huge amounts of data, cloud computing services, machine learning methods and solutions based on artificial intelligence, as well as the Internet of Things, are being combined, allowing users to obtain and analyze information at a relatively low cost. The technological boom could not but affect the healthcare system: today, healthcare automation is one of the most important and complex tasks around the world, requiring huge investments and having a large number of questions and problems.

The integration of medical equipment into a network has already changed the way we work in healthcare. By 2020, the widespread introduction of high-tech methods in medicine will lead to the implementation of the concept of a "Smart hospital".

It is estimated that the Smart hospital market will be worth \$ 63 billion by 2024. The concept is based on the optimization and automation of processes in the information and communication and technological environment of interconnected objects (the Internet of Things). The goal of this environment is to improve existing procedures for providing modern medical care and to open up new opportunities for medicine.

10 key principles of e-health:

- Efficiency.
- Improving the quality.
- Attention to personal data.
- Expanding the patient's capabilities.
- Improving the relationship between the patient and the medical organization.
- Continuing education and professional development through information technology.
- Implementation of secure data exchange.
- Expansion of the healthcare system.
- Ethical standards.
- Accessibility for all

In connection with the above, the main purpose of the article is to analyze the architecture of the medical organization and the integration of digital services into the technological infrastructure of the organization.

The objectives of the study are:

- Description of the architectural approach to the development of a medical organization.
- Analysis of the main top-level business processes in a medical organization.
- Analysis of services in a digital medical organization.
- Modeling of the technological layer of the architecture of a typical medical organization.

2 An overview of the concept of «Smart hospital»

Smart hospitals are institutions that optimize, redesign, or build new clinical processes, management systems, and possibly even infrastructure [1]. They are supported by an underlying digital network that brings together interconnected assets to provide valuable service or information not previously available to provide better patient care [2]. Smart hospitals are built on technologies that allow you to automate clinical, management and support processes, including communication and interaction with patients. As a rule, such technologies include:

- systems for remote monitoring of vital functions of patients by integrating personal devices with information systems of medical centers for remote monitoring of vital signs, telemedicine technologies, "hospital to home" technologies»;
- identification systems (wristbands, labels, badges, etc.) and location monitoring, biometric scanners, patient flow management system;

- "smart building", which implies the management of the state of the environment inside the medical center (temperature, humidity, etc.), a system for monitoring the condition and repair needs in real time, access control, etc.
- high-power network equipment;
- network medical equipment (wearable and implantable devices, stationary and mobile medical and diagnostic equipment);
- integrated information system of the institution (administrative information system, pharmacy and warehouse information system with automated replenishment of medicines and consumables with predictive analysis of the required level of stock, information system of blood transfusion stations, laboratories, imaging, pathoanatomical and pathomorphological services, biobank, sterilization control, etc.);
- electronic medical records of patients, scientific and clinical research data.

Due to digitalization, patient expectations are increasing: they are increasingly using advanced technologies and devices; therefore, the hospital also needs to implement technologies in hospital wards and on an outpatient basis.

Advantages of the "Smart Hospital" concept:

- Interaction with patients. Devices such as touch-screen monitors or tablets can enable patients and their families to improve the patient-doctor relationship. Thanks to the "smart" functions, it will be possible to learn more information about the treatment process, the state of health; while in the hospital room, the patient will have the opportunity to view their medical records, find out the results of tests, find out and make a daily treatment schedule.
- Optimization of the workflow. Through the use of mobile and It technologies, you can improve workflow efficiency, increase productivity when tracking and identifying bottlenecks and service slowdowns. Smart apps will improve hospital navigation for both patients and visitors, as well as for staff. Messaging and routing features can provide step-by-step directions and arrival times to make navigating major hospitals easier and less stressful for visitors.
- Notice to patients. This function can significantly reduce no-show patients and, thereby, reduce the loss of the hospital. Push notifications generated by this software can be sent to patients in your preferred language, informing them about the time of ingestion and accurate hospital room, her address, and to notify of changes in schedule or location.
- Tracking resources of the hospital. Internet of Things (IoT) technologies are widely used in many industries for efficient resource tracking. Hospitals and care centers can use IoT applications to correctly track required assets, their distribution, and location.
- Using data analysis. Smartphones, smart clothes track huge amounts of biometric data that can be used by caregivers to get more detailed information about both individual patients and population groups. The findings could improve the quality of patient care, as well as accelerate research aimed at saving lives.

Problems of creating and integrating a "smart" hospital system:

- Conflict of priorities. Health organizations must provide high-quality care, maintain patient safety (including the security of patient data), prevent infections, ensure financial productivity, comply with regulatory standards, and maintain patient satisfaction. All these tasks, as a rule, should be solved with the help of limited resources.
- The process of becoming a smart hospital takes time. Smart solutions can be implemented one by one, rather than in a single step. At the same time, newer solutions should be integrated with previously implemented ones. Interoperability and cybersecurity are imperative, as hospital devices, systems, and networks must interact with each other in a way that allows data to be analyzed, and that the data is protected and inaccessible to hackers.
- Unstructured data. Unstructured data and legacy systems must be integrated to provide holistic analysis and access to all collected medical data.
- Training and adaptation of personnel. All medical personnel should be trained to effectively use intelligent systems and devices to support their workflow and provide semi-automated data flow management [3].

3 Principles of value-based personalized medicine

Personalized medicine is the adaptation of treatment to the individual characteristics of each patient. This approach is based on scientific advances in understanding how a person's unique molecular genetic profile makes them susceptible to certain diseases. These same studies increase our ability to predict which medical treatments will be safe and effective for each patient, and which will not.

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Personalized medicine is a multi-faceted approach to the treatment of patients, which not only allows for more accurate diagnosis and treatment of diseases, but also makes it possible to detect diseases at an earlier stage, when they are easier to cure. The full implementation of personalized medicine includes:

- Risk assessment. Genetic testing to identify a predisposition to the disease.
- Prevention. Lifestyle changes, therapeutic intervention to prevent the disease.
- Detection. Early detection of the disease at the molecular level.
- Diagnosis. Accurate diagnosis of diseases allows you to develop an individual treatment strategy.
- Treatment. Improved results through targeted treatment and reduced side effects.
- Management. Active monitoring of therapeutic responses and disease progression.

Personalized medicine has a major impact on how medicines are researched and developed; how patients are diagnosed and treated; and how health care directs its resources to maximize patient benefits.

4 Materials and methods

To apply the concept of "Smart Hospital", IT is necessary to use IT support, and the requirements for the technological infrastructure to ensure the implementation of processes are set. The methodology of an integrated management system for medical organizations is needed. The use of an architectural approach is the optimal solution for the formation of this methodology [4].

The enterprise architecture is a single whole of such elements of the management system as business processes, functional and organizational structures, material and cash flows, information systems and applications, data, document management, and technological infrastructure objects.

There are different methods (standards) for architecture development:

- Rational Unified Process (RUP). The software development and implementation process is iterative in this approach, with each new iteration adding functionality to the software architecture.;
- UN/CEFACT Modeling Methodology (UMM). This methodology is a methodology for building business processes and information models.
- Enterprise Architecture Description Standard IEEE1471-2000 (IEEE Computer Society 2000). The standard is a theoretical framework for defining, analyzing, and describing system architectures. IEEE 1471 focuses on software systems for information and complex systems.
- The standard describes the architecture TOGAF (The Open Group Architecture Framework). The method was positioned by the developers as a "tool for developing information system architectures".
- Architecture Capability Framework. It examines the organization, processes, skills, roles, and responsibilities required to create and use architecture functions within an enterprise.
- An Architecture Development Method (ADM) that provides a "way of working" for architects [5].

5 Architectural approach to the development of a medical organization

The concept of architecture is inextricably linked to the concept of the system. For example, when studying the design of information systems, the architecture of the system is determined by the class and structure of information systems. The concept of enterprise architecture is based on the principles of a systematic approach.

Enterprise architecture is typically used as a tool for managing the day-to-day operations and future development of a company (Fig.1 shows a representation).



Fig. 1. Enterprise architecture as a management tool

An enterprise management approach or standard is a structured set of methods and process steps for creating and maintaining enterprise architecture [6]. Methods usually define the different stages of the architecture lifecycle, what results should be obtained at each stage, and how they are tested. This chapter will look at the TOGAF standard mentioned earlier.

The TOGAF (The Open Group Architecture Framework) architecture description standard describes the structure and method of developing enterprise architectures. Within a medical organization, TOGAF will have the following main components:

- Architecture Capability Framework, mentioned earlier.
- ADM, which is considered the core of TOGAF and consists of a step-by-step cyclical approach to the development of the overall enterprise architecture (Fig. 2 shows the approach).
- Architecture Content Framework, which examines the overall enterprise architecture, consisting of four closely interrelated architectures (Fig. 3 shows the layers):
 - business architecture;
 - data architecture;
 - application architecture;

— technological architecture.

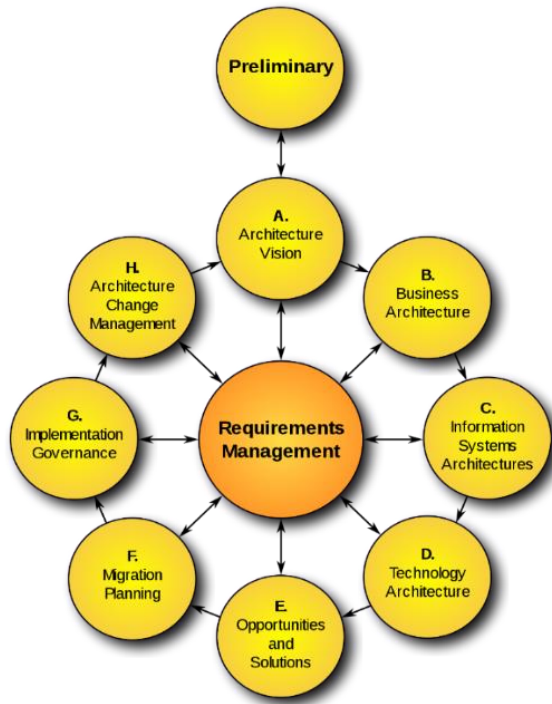


Fig. 2. Architecture Development Method (ADM), TOGAF

To date, TOGAF is one of the most conceptually appropriate methodologies and corporate architecture framework used by leading global organizations to improve business performance [7]. This methodology allows to identify different elements of the enterprise architecture at different levels of abstraction and gives architecture developers the opportunity to choose architectural models, examples, and experience from different industries. The TOGAF standard ensures the openness and compatibility of the developed models. In addition to the ability to create a holistic conceptual picture describing the activities of the organization, continuous interaction with business representatives, and considering their requirements, the developers of TOGAF actively interact with the developers of the ArchiMate modeling language. The standard allows you to consider the architecture "as is", to form requirements for the target architecture with the help of motivational expansion, to develop a target model of the corporate architecture of a medical organization considering medical and IT trends, to create a transition plan for the target architecture [8].

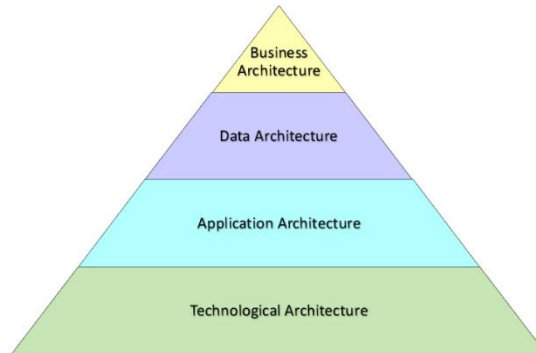


Fig. 3. Enterprise architecture model (TOGAF standard)

6 Results

In the previous sections of the article, the concept of a "Smart Hospital" was analyzed and the principles of value-based personalized medicine were defined. Using the given reference model of the enterprise architecture, in the following sections of the study, the authors will present their vision regarding the reference model of the architecture of a medical organization based on the identified main business processes.

The top-level of digital medical organization processes consists of several processes:

- admission to the hospital;
- being in the operating room;
- stay in the hospital;
- discharge from a hospital;

6.1. Admission to the hospital

The admission of a patient to a medical institution is a process that is often neglected, but this does not make the process any less important. It is this process that allows the patient to "enter" the system of the medical institution. And how smoothly and conveniently this happens affects the further results of the institution's activities and the client's satisfaction with these results. In the table 1 admission services are presented.

Table 1. Admission to the hospital services

Service	Description
Real-time patient queue management	Staff can use a personal computer or mobile device to call the next patient in the queue. LED indicators to display the numbers of issued e-tickets in the queue and the waiting time in real-time. Patients can see the information on the display. Medical institutions can also use the

	display queue to represent the appropriate medical information.
Information services at the reception	The registration cost dashboard with information on doctors, their schedule, a description of the services of the medical center, the cost of the paid services, when patients receiving plaintive appeals, and reviews about the work of the center
Patient appointment service	Patients are recorded via the web or mobile interface, as well as through the information desks in the medical center.
SMS notifications of patients about appointments to the medical center	When making an appointment, the patient is offered an SMS notification service, with which he can confirm the appointment, get information about it, and, if necessary, cancel it.
Tracking the KPI of registration employees	The system monitors and evaluates key performance indicators based on the data obtained on the results of employees' work
Online view of the current queue in the branches of the medical center	The system calculates and predicts the approximate time depending on the patient's treatment category and the average doctor's appointment time, distributing the flow of patients in the queue.

6.2. Hospitalization

The use of services in the hospital removes the burden on the hospital staff from filling out a huge number of papers manually, gives a complete picture of what is happening in the hospital, reduces the likelihood of staff errors, stores all data in one place, eliminating losses, automates business processes occurring in the hospital. In the table 2 hospitalization services are described.

Table 2. Hospitalization services

Service	Description
Thermal imaging sensors	Used to detect pathologies that are difficult to diagnose in other ways, including the detection of malignant tumors.
Infrared sensors	Can be used, for example, to determine whether your hands have been washed
Sensors for monitoring patient movement	Provides healthcare professionals with the most important information about the patient's condition
Sensors with AI for remote monitoring of required health indicators	Allows to remotely monitor such indicators as temperature, respiratory rate, sweating, pulse rate, heart rate, pressure.
Sensors for monitoring the level of saline in the dropper	Allows to carry out continuous monitoring of the level of saline solution to monitor the patient's condition and rapid response
RFID tags for identifying and tracking patients, staff, and medicines	Using the label on the package, you can simplify inventory, track the product and protect yourself from counterfeit goods.

	The patient's wristband label may contain information about the patient's identity, his placement in medical institutions, the data on the title page of the inpatient card, information about the allergic history, drug intolerance, the diagnosis, and the attending physician.
Telepresence robots: multifunctional, portable and audiovisual robotic systems	Such systems virtually connect patients and doctors, for example, in cases where the doctor is not physically able to be near or there is a risk of infection
Patients telemetry	Allows to collect data about the physical condition of the patient and analyze the data obtained
The location of the patient; The location of the staff; Tracking drug flows	The real-time location system automatically identifies and tracks the location of objects or people in real time using tags and sensors
Assessment of the hygienic condition of surfaces (wards, equipment); Conducting diagnostic and functional tests in the ward; Equipment monitoring	Allows to pre-evaluate and, in some cases, remotely check the ward and its equipment for errors, contamination, or malfunctions.
Predicting the outcome of the disease	Based on the obtained data, it allows the system to search for patterns and make forecasts for diseases and their outcome, keeping in mind the patient's indicators
Telemedicine/telepresence	Telemedicine is the remote provision of medical services
Predictive diagnostics	Diagnosis based on the analysis of the results of genetic studies. It allows you to predict the development of diseases even without visible symptoms, which reduces the risk of complications and deaths.
Access to the electronic patient card (MIS)	Prompt access to the patient's card, which allows you to immediately use the available information, check it for veracity, and can notice the risks that have appeared [9].
Access to the patient's daily schedule	The system makes a request to the available information on the patient and shows the patient's daily schedule, consisting of activities aimed at recovery and discharge.
Creating a schedule for taking medications	The system makes a request to the available information on the availability of medicines and generates a schedule for taking medicines. The schedule is formed based on the recommended method of use from the manufacturer of the drug.
Transfer of data from bedside devices	Bedside devices are equipped with special sensors that send the data obtained by the analysis directly to the doctor for further observation

6.3. The operating room

One of the areas where advanced technologies have been introduced for a long time is operational activities. Speaking about technologies and IT services from the point of view of a Smart hospital, the services presented in Table 3 can be highlighted.

Table 3. Services in the operating room

Service	Description
Access to the electronic patient card (MIS)	Prompt access to the patient's card, which allows you to immediately use the available information, check it for veracity, and can notice the risks that have appeared.
Interaction with a Robot-assisted surgical system	The implementation of medical procedures
Patient telemetry	Allows you to collect data about the physical condition of the patient and analyze the data obtained
Voice recognition	The voice recognition system is used in cases where the patient has problems with hand motor skills, is unable to press buttons or the screen, or is unable to move.
Integration with other services	If there is a production need or the patient's desire and capabilities, it is possible to integrate with services to increase convenience and efficiency.
Telemedicine/telepresence	Provides hardware at the point of delivery of medical services, designed primarily for collecting primary data from patients, including using diagnostic equipment

6.4. Discharge from a hospital

Moreover, an important process in working with patients is his/her discharge from the ward and subsequent monitoring of his/her condition. Both medical and non-medical personnel are involved in the discharge process. Smart hospital services presented in Table 4 will simplify and optimize the work of all participants in the process.

Table 4. Discharge from hospital services

Service	Description
Real-Time Locating System (RTLS)	The real-time location system automatically identifies and tracks the location of objects or people in real-time using tags and sensors
Instant notification system for patient discharge	At discharge, creates an appropriate notification that is sent to specific doctors
Notifications to non-medical staff about changing the bed, about the need for cleaning when the patient is discharged, about the release of the ward	From time to time or under certain conditions, the program sends a notification to further the work of the employees

Automatic generation of reports according to the statement

Automatic creation of the discharge epicrisis, conclusions, prescriptions, data on the course of treatment and prescribed drugs, recommendations after discharge, etc.

Thus, all the services listed in this chapter can be represented as a model (see Fig.4). It displays the upper level processes and functions of the hospital [], and the Smart Hospital services described above are marked at the intersection.

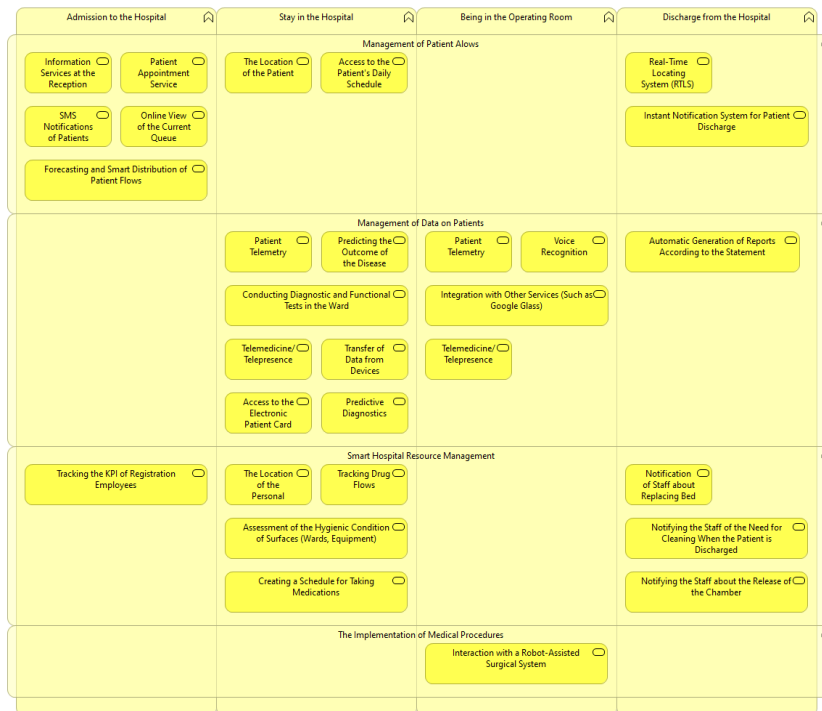


Fig. 4 The upper level of the processes of digital medical organization

7 Creating a service architecture that supports Smart Hospital operations

When modeling the activities of medical organizations, there are a number of specific features of this industry that affect the choice of approach to identifying processes: a patient-oriented approach, a pronounced matrix management system based on functional and administrative subordination, an individual trajectory of patient treatment, a high degree of regulation of medical care processes and related processes, including certain requirements for document management in healthcare.

The functional model of the enterprise is one of the key elements of the business architecture. It provides an understanding of the business structure is the basis for the formation of end-to-end and functional processes, provides input information for the formation of the organizational structure, and can also serve as a basis for subsequent feature-oriented automation [10].

The main business processes are service-oriented processes designed to create an enterprise and generate revenue.

Management processes are processes that cover the entire set of management functions at the level of each process and the business system as a whole.

Auxiliary-processes designed to support the execution of key business processes and their specific functions

The structure can be represented using a set of applications that implement key information technology services. This set of applications includes:

- electronic medical record;
- system for the provision of outpatient care;
- the system of providing inpatient care;
- clinical monitoring system;
- anesthetic monitoring system;
- accounting system;
- personnel management system;
- Pharmacy POS system;
- laboratory medical information systems.

For example, we can consider in more detail the application "hospital care system" (Fig. 5 shows an example):

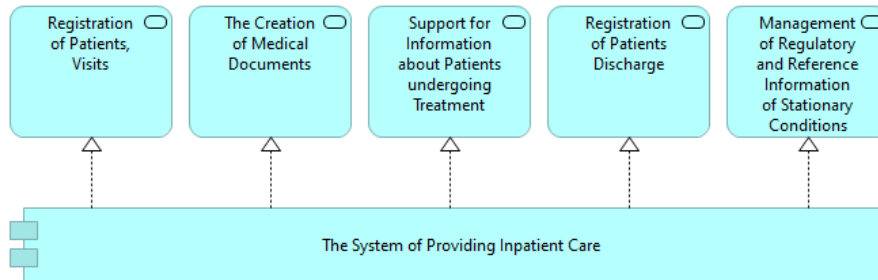


Fig. 5. Component of the application «System of inpatient care»

At the same time, according to the upper level of processes, it is necessary to create a technological architecture for each process using the necessary services (Fig. 6 shows an example).

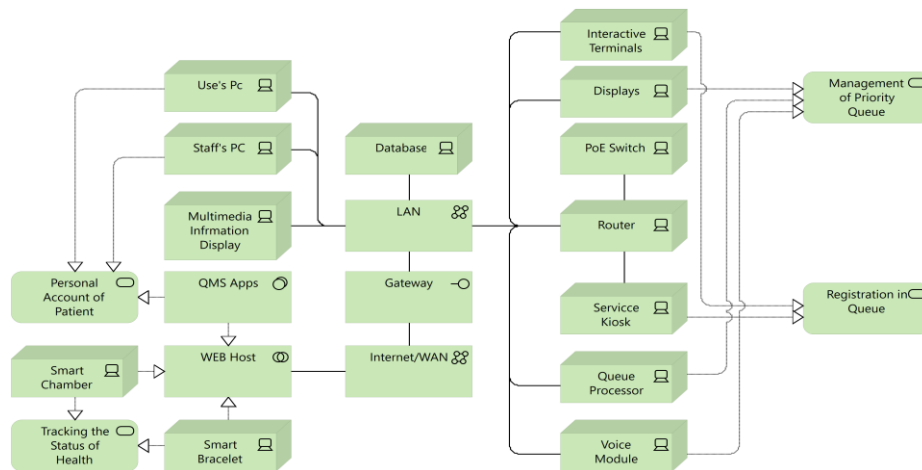


Fig. 6. Technological architecture of admission to a medical institution

7 Trends in digital infrastructure solutions for the implementation of the Smart Hospital concept

The modern market offers more and more solutions to ensure the Smart Hospital operation. These devices are becoming useful not only for the internal processes of staff, but also for simplifying the interaction with the user and increasing his/her level of satisfaction with the services provided, for example, systems and devices for managing the flow of patients. The variety of devices on the market allows medical organizations to choose the best option for them from a number of all kinds of steles, telemedicine stands, tracking bracelets and much more.

Let's consider a few examples of such devices.

An interactive information stand allows patients to view on-site information about the clinic, schedule doctors, make appointments, receive certificates and coupons for electronic queues, pay for paid services, and so on. This allows us to make the process of patient admission much more transparent and faster, and also to strengthen control over queues in order to avoid conflict situations.

Services that help implement an infrastructure solution:

- patient appointment service;
- real-time patient queue management;
- information services at the reception [11].

Smart watches with the help of sensors and sensors allow you to monitor the patient's condition and location. The device screen allows you to display health data for a more accurate patient survey and self-monitoring of the patient's health. All information about the patient's health is sent and stored on the hospital's servers and is available for viewing by the doctor.

Services that help implement an infrastructure solution:

- Sensors with AI for remote monitoring of required health indicators;

- RFID tags for patient identification and tracking [12].

8 Conclusion

In today's world, with an extremely fast pace of life, electronic healthcare systems and smart hospital projects have become an absolutely necessary and important issue. Smart Hospital will allow people to save time and take better care of them. In addition, it will help doctors organize their schedules more efficiently, allowing them to avoid long waiting lists in hospitals, while medical staff can easily manage their time.

Another significant advantage is that the e-health system allows both patients and doctors to get all the necessary information about the state of human health at any time when it is necessary. By integrating with existing hospital technologies and developing new Smart Hospital software, we help caregivers focus on delivering care and spend less time on things that can be automated and performed with smart systems.

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