Digital Twins, Internet of Things and Mobile Medicine: A Review of Current Platforms to Support Smart Healthcare

I. Volkov^{a,*}, G. Radchenko^{a,**}, and A. Tchernykh^{a,b,c,***}

^a South Ural State University, Chelyabinsk, 454080 Russia

^b CICESE Research Center, Ensenada, B.C., 22860 Mexico

^c Ivannikov Institute for System Programming of RAS, Moscow, 109004 Russia

* e-mail: volkovia@susu.ru

** email: gleb.radchenko@susu.ru

*** email: chernykh@cicese.mx

Received July 8, 2021; revised July 29, 2021; accepted August 10, 2021

Abstract—As the population grows, the need for higher-quality medical services increases, as well as the demand for information technology in medicine. The Smart Healthcare concept brings various approaches to address the acute problems encountered in modern healthcare. In this paper, we review the main problems of modern healthcare and analyze existing approaches and technologies in digital twins, the Internet of Things, and mobile medicine. We will also analyze the key features of modern platforms that support Mobile Health Applications. Finally, based on our analysis, we will propose the concept of Smart Healthcare Platform, focused on solving tasks related to supporting the development of Mobile Health Applications, including organizing access, management, and sharing of user data.

DOI: 10.1134/S0361768821080284

1. INTRODUCTION

Modern medicine faces multiple challenges related to the increasing need of the population for healthcare services. The demand for solutions from this area is driven by the growing volume of patient data, increasing technological capabilities, and the demand for fast and efficient healthcare processes and systems.

According to a 2010 study [36] the health information technology market grew from \$99.6 billion in 2010 to \$162.2 billion by 2015. Now, going back to the same source [35] we can see that in 2019 this market was at 187.6 billion and is expected to climb to 390.7 billion by 2024. Thus, we can see the exponential growth of this market in the previous decade, which is also projected for the next decade. The crisis caused by the COVID-19 epidemic only emphasizes this trend.

Currently, specialists in Digital Twins technology, mobile medicine, and the Internet of Things are working on healthcare problems. All of these technologies are grouped in a field called Smart Healthcare. Smart healthcare is a system that addresses healthcare challenges with modern technologies and approaches to treatment and patient monitoring.

The most critical components of Smart Healthcare are platforms that support the collection of medical data and make it available to the developers of final solutions in the form of web or mobile applications. In this article, we explore the current state of the

Smart Healthcare market, highlighting the critical approaches that distinguish personalized medicine approaches. Mainly we will explore the concept of mobile medicine and the platforms that support the development and functioning of mobile medical applications.

The article is organized as follows. Section 1 provides an overview of the Smart Healthcare concept and the so-called Digital Twins in modern healthcare. Section 2 focuses on the most critical approaches in Smart Healthcare. Section 3 provides an overview of mobile medicine in Smart Healthcare. Section 4 is devoted to the review of the modern mobile Healthcare platforms. In the last section, we propose a concept for the Smart Healthcare Platform.

2. THE CONCEPT OF SMART HEALTHCARE

The concept of Smart Healthcare is part of the Smart Planet concept proposed by IBM in 2009. A Smart Planet is an intelligent infrastructure that uses sensors to acquire information, transmits that information through the Internet of Things (IoT), and processes it using supercomputers and cloud computing [15, 44].

In this concept, Smart Healthcare is a healthcare system that utilizes technologies such as wearable devices, IoT, and mobile Internet to provide dynamic

access to information, connect people, materials, and institutions relevant to healthcare, and then actively manage and respond to the needs of the medical ecosystem intelligently [26].

To understand why Smart Healthcare is a rapidly growing field in medicine, we review the problems that the concept of Smart Healthcare focuses on and the leading technologies and approaches used to solve these problems.

2.1. Problems of Modern Healthcare

The critical problems of modern healthcare are caused by such factors as [7]:

- an increase in the population and in life expectancy, which leads to an increase in the number of sick people who need the attention of doctors;
- the difficulty of monitoring patients' adherence to prescribed treatment;
- an increase in the number of older adults [18] who require care and supervision;
- urbanization, which increases the chances of epidemics caused by the compact residence of large numbers of people. Such epidemics can lead to sharp jumps in the number of patients requiring medical care. One recent study, which was based on the current crisis caused by the COVID-19 epidemic, shows that high population density in cities causes accelerated growth of epidemics [4];
- a shortage of healthcare professionals who cannot maintain an adequate level of healthcare services to meet the growing needs of the population;
- an increasing cost of medical services, mainly affecting patients with chronic diseases. For example, in the U.S., as of 2016, the cost of diabetes care was \$245 million and has increased by 21% over nine years [29].

These problems can be solved by applying modern technologies and approaches to the treatment of patients. For example, approaches in which the clinic and physicians are at the center of the process and patients do not have an active role in the treatment process are primarily used today. However, allowing patients to take an active role in tracking and managing their health can help decentralize healthcare [20], reducing the burden currently placed on physicians and increasing the effectiveness of the treatment provided.

2.2. Digital twins in Smart Healthcare

Application of the “Digital Twins” concept today can be noted as one of the most striking trends in the digitalization of various industries. Emerged from the aerospace field, Digital Twin today is actively promoted to solve problems in industry and management of complex systems (such as “Smart Cities”). In these areas, the concept of the Digital Twin is quite estab-

lished. Among other things, it has allowed us to separate the concepts of a digital model, digital shadow and digital twin, the difference between which lies in the extent to which automation of data and control flows is provided, between a physical object (system) and its Digital Twin [13, 41]. This approach to the definition can be called justified because the use of the Internet of Things technologies, new approaches to the organization of data transfer, and providing control in the real-time lead to the fact that it is possible to provide synchronization of the state of the physical and digital twin in near-real-time.

The article [27] points out that developing a Digital Twin can be a very complex and costly task and can also increase the complexity of monitoring patient health in a hospital. Therefore, research related to digital twins needs to determine which data contribute most to the predictability of outcomes, how these outcomes can be evaluated, and how this approach can be cost-effectively integrated into healthcare. Ultimately, however, Digital Twins can improve diagnostic and monitoring capabilities, improve therapy and patient well-being, reduce economic costs, and expand treatment options and patient options when adequately implemented.

However, in healthcare, the concept of a Digital Twin is not yet so clearly defined due to the incredible complexity of the human being, an object of the physical world, for which a Digital Twin must be created. As for the components of industrial systems today, there is a hope that modeling will provide the desired accuracy of results. But unfortunately, it is much more challenging to offer universal methods and approaches to modeling the human being. Also, despite breakthroughs in creating new sensors and data collection methods, obtaining up-to-date data on key indicators of the human body in an operational mode is a difficult task, which can be implemented, most often, only in laboratory clinical research settings.

3. SMART HEALTHCARE APPROACHES

Among the most popular approaches in Smart Healthcare are individualization, continuous health monitoring, telemedicine, and disease prevention.

3.1. Individualization

The concept of disease resulting from a causal factor is overly simplistic. Disease development can be predicted better by understanding that each individual has an initial susceptibility to various diseases and that person's health is affected by environmental factors [24]. While previous approaches to medicine were static and focused on getting rid of the effects of a disease, the new approaches are dynamic and take into account that diseases develop over time (see Fig. 1).

Individualization is an essential factor here — each patient's course of illness, its cause, and the body's

Fig. 1. Comparison of traditional and personalized medicine.

response to medications can be individualized. Because of this, the choice of treatment approach and patient monitoring can be affected by many factors, depending on the patient's body, their reactions to medications, their medical history, and their physiological parameters.

Thanks to modern technology, each person's health data can be collected, stored, analyzed, and compared with data from other patients. With the proper use of technology, there will be no need for a lengthy analysis of a patient's response to the treatment applied to them, as the system will be able to select medications, dosages, and treatment plans almost immediately, focusing on multiple factors associated with a particular patient [34].

For example, the authors of [1] consider the possibility of using IBM Watson to help doctors work with patients with cancer. Clinical trials are responsible for many medical advances in cancer prevention, detection, and treatment. However, just as no two people are alike, no two cancer diseases are alike. Currently, coordinators analyze an average of 46 criteria to select patients for trials. This extensive range of data, which requires analysis and comparison with each patient, makes it challenging to accomplish this task without advanced analytical capabilities. With IBM Watson, a physician can automate the analysis process by providing patient-specific health information to the system. Watson analyzes patient data, comparing patient data to clinical trial databases, and offers the physician

options for specific clinical trials appropriate for that patient.

However, the personalized medicine trend in healthcare is a relatively new approach; it is being studied and developed thanks to advances in information technology and the emergence of smart devices in recent years. The authors of [12] point out that the effectiveness of individualization has not been sufficiently studied yet. In real case scenarios, a personalized approach may not effectively improve risk prediction, reduce costs, and improve public health for common diseases, as presented in the research articles.

In the article [9], the authors point out that data-driven decisions need to be better regulated because they raise partly unrealistic expectations and concerns. They also highlight the need to improve computational methods in clinical practice to provide measurable benefits.

3.2. Mobile Medicine

Mobile medicine today is one of the critical approaches to solving Smart Health challenges. A wealth of studies on Mobile health (mHealth – Mobile Medicine [8]) focused on using mobile technology to monitor and influence the patient's condition continuously.

Mobile medicine includes technologies related to mobile applications and technologies of the Internet

Fig. 2. Mobile medicine data sources and critical components.

of Things, peripheral devices, computer vision, and telemedicine (see Fig. 2).

In 2016, doctors saved a man's life with the help of mobile medicine. When a 42 yr old man was admitted to the hospital with a seizure, doctors looked at his Fitbit Charge HR fitness tracker's vitals, and it helped them make important decisions about the patient's future treatment path [21].

Mobile medicine encompasses many areas of development, among which the following can be noted [25]:

- *Wearable sensors* – bracelets, watches, headbands, patches, headphones, and clothing that provide passive and continuous monitoring of a person's biometric indicators;

- *on-chip laboratories* (complete analysis microsystems) are miniature instruments that allow one or more multistage (bio) chemical processes on a single chip with an area ranging from a few mm² to several cm² and using micro- or nanoscopic amounts of samples for sample preparation and reactions;

- *intelligent image analysis* - the high quality of smartphone cameras made it possible to use them for photometric diagnostics both with and without additional devices (for example, recognizing an ear infection using an otoscope).

3.3. Continuous Health Monitoring

The growing number and variety of wearable devices, as well as the gradual decrease in their cost, make it easier to integrate them for monitoring patient health. Thus, mobile medicine is an essential component for implementing continuous health monitoring, which opens up new possibilities for doctors, patients, and researchers.

"Internet of Medical Things" (IoMT) is a separate category of the Internet of Things, the distinguishing feature of which is the use of sensors for monitoring and controlling the health of patients [16]. Such sensors enable the collection and processing of critical biometric data about a person's health in real-time.

In [30] the leading modern technology providing the growth of the health monitoring field with the possibility of its mass implementation is distinguished by unobtrusive sensing and wearable devices. The most commonly measured parameters by those devices include:

- ECG;
- ballistocardiogram (BCG);
- heart rate;
- blood pressure (BP);
- blood oxygen saturation (SpO2);

- blood glucose levels;
- body temperature;
- posture;
- physical activity.

The main difference between these medical devices lies in the ability to integrate them into the user's daily life so that these devices won't disrupt the regular daily routine of the person, but rather give them the benefits by displaying detailed information about various aspects of their health on the screen of their mobile device. Such an approach makes it possible to collect and store important data about a person's health over a long period autonomously and regularly, analyze the gathered data, compare it with data from other patients, and help physicians make quick decisions based on current health indicators.

In [17] studying this approach, the authors propose a solution to monitor older adults' daily routines and behaviors to detect abnormal behavior without interfering with their lives. Such a solution could help care for older adults who live alone with dementia or Alzheimer's disease.

3.4. Telemedicine

Advances in communication technology have given doctors and patients new opportunities to interact with each other. For example, telemedicine can manifest itself as a remote real-time video conference with a patient and the ability to instantly exchange text or media information about a person's health. Telemedicine can eliminate the need for the physician and patient to be physically present in the same place to organize the treatment process.

Physicians can receive information from patients about their health much more quickly and conveniently and provide the patient with feedback about their health state and possible changes in the therapy they need to make.

These technologies are significant when interacting with:

- patients with chronic diseases who require constant monitoring;
- patients who are located in remote places and cannot quickly and safely get to a doctor for consultation or treatment adjustments.

Integrating telemedicine in the healthcare field can result in:

- possible cut in costs for healthcare providers;
- increased patient satisfaction with the treatment process;
- lower patient costs for chronic diseases (such as heart disease, diabetes, respiratory disease, or cancer) [2].

A significant area developing in telemedicine today is the use of virtual reality (VR) technologies. In 2009, the results of a study on the use of VR technology for

stroke rehabilitation were presented [19]. As part of the study, patients were divided into two groups. The first group underwent rehabilitation remotely under the control of a doctor with the help of virtual reality; the second group underwent rehabilitation in a local hospital. At the end of the study, no significant difference was found between the two groups, which shows the effectiveness of virtual reality technology.

Studies have also been conducted on the use of augmented reality (AR) technology. For example, in [28] the authors propose a technology that allows physicians in remote locations to be trained to perform complex medical procedures, such as ultrasound scans, without visual intervention. The mentor's hand gestures are captured using Leap Motion technology and virtually displayed in the space of the trainee's HoloLens glasses.

3.5. Disease Prevention

Thanks to the widespread introduction of mobile devices and wearable sensors, users can know in advance if they are likely to become ill. A relevant example here would be the notification systems developed by Apple and Google about contacts with people infected with the COVID-19 virus. The presence of a cell phone in the vast majority of the population allows devices to anonymously collect and store information about the duration and number of a user's contacts with other people. This allows the system to anonymously notify all other people who have had contact with them of their possible risk of contracting the disease if one of the users tests positive for the disease as well [37].

In addition to detecting infection through contact tracing, modern technology makes it possible to analyze a person's health status and predict the development of diseases based on historical data on the person's biomedical indicators and by comparing it with the historical data of all of the other users. Thus, the system can be trained to detect deviations from the standard human indicators and assume the cause of these changes and their possible further development. For example, in the article [6], the authors propose a machine learning algorithm, the implementation of which allows achieving an accuracy of 94.8% in predicting the risk of ischemic stroke for a patient being observed in a hospital.

Another example of mobile medicine for disease prediction is the neural network algorithm proposed in [22] that uses voice recordings to determine whether a patient has Parkinson's disease. The authors of the paper claim it to be 100% accurate.

4. MOBILE MEDICINE FOR SMART HEALTHCARE

Mobile devices are one of the main ways to easily collect data about a user's condition using mobile

apps. Today, many applications collect information about almost any disease by manually entering data by the user or reading data from sensors.

To understand how to use mobile technology in healthcare effectively, let's look at the existing problems in this area, possible use-cases for these technologies, and existing commercial solutions.

4.1. Technology challenges in Mobile Medicine

Biomedical sensors are now prevalent mainly as off-the-shelf devices connected to an application on a mobile device via Bluetooth or Wi-Fi. Today, the data collected by such devices are limited to the types of indicators such as heartbeat, physical activity during the day, and sleep quality.

Currently, the data variety provided by wearable devices cannot provide a sufficient level of detail of human health information to provide accurate interpretations.

In 2016, doctors saved a man's life with the help of mobile medicine. When a 42 year old man was admitted to the hospital with a seizure, doctors looked at his Fitbit Charge HR fitness tracker's vitals, and it helped them make important decisions about the patient's future treatment path [21].

But although there have been documented cases where wearable devices have helped save a person's life [21], more specific data collection is needed for a more detailed analysis of a person's health status.

The crucial gap preventing the mass adoption of these technologies is the production, promotion, and implementation of mass-market sensors. On the one hand, such sensors should be affordable and convenient for the patient to wear at all times. But, on the other hand, they should function well enough to support reliable data collection and transition for processing in a mobile device or a cloud service.

Today, there is no unified approach to collecting and processing data from such sensors. This results in each developer creating their applications or web services to process and store the data. As a result, users do not have straightforward mechanisms to enable seamless merging and centralized data management from different vendors.

It should also be considered that wearable devices can generate a considerable amount of information, several GB in one day from just one device [7]. Of course, not all generated data should be transmitted over the network in a raw format. But the increase in the number of wearable devices and the information they generate leads to the need for an appropriate network architecture, which would be able to stably, reliably, and timely transmit the data received to the interested parties.

4.2. Technology Challenges in Mobile Medicine

The main problem of mobile applications in the healthcare industry is the lack of mechanisms for combining information collected by different applications from different sensors. Users install several applications on their devices to deal with medical data generated by various sensors. Each of the applications stores and processes the user's data in its format without exchanging this information with other applications.

Apple has the Apple Health app on its devices, with which Apple is trying to solve the problem of data fragmentation by providing an interface for applications to exchange data. The main problem is that this is a commercial product developed for the Apple ecosystem, limiting the use of this service by third parties.

Another problem is that developers don't need to implement data sharing with HealthKit¹. Apple Health currently does not provide the user with an in-depth analysis of the data stored in the app, and developers have no way to transfer data anywhere other than this app. And since most apps are now developed simultaneously for both iOS and Android systems, the lack of ability to exchange data between these platforms leads to developing custom web services, which support storage and processing of the data received.

Another critical problem with mobile healthcare applications is the difficulty of involving patients in treating and monitoring their disease. Gamification techniques are used to solve this problem. An extensive study [23] reviewing 46 articles on gamification in healthcare was conducted in the article. According to the study results, most of the applications positively impact the patient's health, helping in following the prescribed therapy, monitoring the disease, and improving one's health and one's disease with increased motivation for therapy.

However, as the authors point out, most studies were conducted with the patients using the application for short periods of time. Because of this, it is difficult to say how effective the use of gamification is in the long-term treatment. Also, considerations should be given to the patient's ability to cheat the system to gain more progress in the game, sacrificing the validity of the data entered into the app.

4.3. Using Mobile Medicine and Internet of Things Technologies for Patients with Chronic Diseases

Patients with chronic heart disease require continuous monitoring of their condition to prevent critical situations before they occur. According to WHO statistics, about 230 million people have heart problems, and up to 3 million people die from these problems each year [14]. Internet of Things technologies can significantly simplify and speed up collecting data

¹ <https://developer.apple.com/health-fitness/>

about the condition of the patient's heart, transmit this data in real-time to the doctor and analyze it [16].

Large companies are now also addressing this problem; for example, in 2019, Apple released the Apple Watch Series 4, which allows real-time ECGs monitoring of the heart and notifications delivery about user's health abnormalities they have identified that need to be addressed [39].

Another disease that requires constant monitoring is diabetes mellitus. People with this disease need to keep track of their medical and nutritional records, recording these data about ten times a day on average.

To solve the problem of collecting and analyzing diabetes data, some devices can automatically store and synchronize data such as blood sugar levels.

Such devices can be divided into three groups:

- *glucose meters*, with the ability to synchronize data with your cell phone;
- *systems for continuous monitoring of blood sugar levels* with the display of this information on the device itself with the possibility of saving the data to a computer;
- *a continuous sugar level monitoring system* that can read the data through the NFC chip on the device itself or in the cell phone.

The study presented in [10] suggests that these systems can significantly facilitate collecting data on the user's sugar levels. As a result, they improve the patient's level of diabetes compensation and achieve more stable blood sugar levels. This is confirmed because the average sugar level became closer to the target level in the patients who took part in the study than before the study began.

Some products can also analyze information about a person's blood glucose levels and carbohydrate intake, providing the patient with autonomous correction of blood glucose levels with automatic insulin injections [31]. Such technologies are still under development, but the development of such projects indicates research in this area and the possibility of further integrating mobile medicine and IoT into future developments.

4.4. Commercial Mobile Medicine Solutions

In a March 21, 2016 presentation, Apple announced two platforms: ResearchKit² and CareKit³.

ResearchKit provides an API for collecting medical indicators of patients with various diseases. The purpose of the platform is to aggregate and analyze this data by specialized disease research institutions. For example, this platform is already in the process of collecting information about people with Parkinson's

disease, in which 9,520 people have participated and agreed to share their scores [3].

On the other hand, people's increasing desire to share their data, including medical data, can have unintended consequences and is extremely risky. Before the advent of mobile technology, it was impossible to collect daily information about a patient's health so easily. There are risks that the mHealth platform may not be used for the purposes intended by its creators [11]. Therefore, the data obtained through technology and the opportunities it provides should be treated with considerable caution.

The second platform, CareKit, is a framework that helps develop applications that help users monitor their health. It also allows developers to simplify developing applications that help collect users' health data for clinical research.

Given the increasing amount of data collected through sensors and manual entries by the user, there is a need for a service that can aggregate all the data obtained from different services in one place for subsequent analysis. As a solution to this problem, Apple has developed the Apple Health service, which allows users to store data obtained through sensors in Apple devices and allows developers to synchronize users' data obtained by third-party applications or devices from Apple Health.

However, this solution imposes limitations on the choice of smartphones and wearable devices that users use and does not allow real-time access to the data for attending physicians or relatives. We propose to develop a comprehensive system that will help all stakeholders, including:

- patients who would enter data about their health and lifestyle;
- medical personnel;
- medical researchers who organize studies that require large amounts of data from a variety of participants.

5. OVERVIEW OF MOBILE MEDICINE PLATFORMS

When selecting projects for analysis, we were guided by the following points:

- the project documentation is freely available;
- the project has real-world examples of use;
- the project does not focus on maintaining data on a specific disease but rather on tracking the individual's overall health.

To better understand the differences in existing mobile medicine and Smart Healthcare platforms, we compared currently available solutions based on the following criteria (see Table 1):

- Platform lifetime;
- Native AppStore application availability;
- Native Google Play application availability;

² <https://www.apple.com/ru/researchkit/>

³ <https://developer.apple.com/carekit/>

Table 1. Comparison of mobile medicine and smart healthcare platforms

Platform Features	Apple HealthKit	Google Fit	Microsoft HealthVault	HealthBox	Open mHealth
Platform lifetime	2014 – present	2014 – present	2007–2019	2020 – present	2011–2019
Native AppStore application	+	+	+	–	–
Native Google Play application	–	+	+	–	–
iOS SDK	+	–	+	–	–
Android SDK	–	+	+	–	–
Server-side API	–	+	+	+	+
Web interface	–	–	+	–	–
Social sharing	+	–	–	–	–
Number of health data types	160+	31+	80+	82	89
Data types customization/personalization	–	+	–	+	+
Data synchronization method	iCloud	Google Cloud	Microsoft Cloud	Own server	Own server
Data sharing with family members or physicians	+	–	+	–	+
Self-hosted server requirement	–	–	–	+	+
Direct access to platform data from 3-rd party developers.	–	–	+	+	+

* Available starting from iOS 15

- iOS SDK availability;
- Android SDK availability;
- Server-side API – whether the platform allows you to receive, send and edit the data it contains through any data exchange protocol from another web application;
- Web interface – the ability to manage data via the native web interface of the platform;
- Social sharing – whether the platform has the opportunity to share medical data with other people;
- Number of health data types monitored through the platform;
- The ability to customize/personalize data types – whether the platform allows you to configure data types not initially provided by the developer;
- Data synchronization method – technology used to synchronize the data;
- Data sharing with family members or physicians – at least one opportunity to share data other than creating a screenshot has been implemented;
- Self-hosted server requirement – whether you need to deploy your server to work with the platform;
- Direct access to platform data from 3rd party developers – whether the developer needs additional software to collect and analyze data from the platform.

Let's consider mobile medicine platforms that meet our defined parameters.

5.1. Apple Health

Apple Health was developed by Apple in 2014 and is still being maintained and developed today.

The central part of the platform is the Health mobile app, which is pre-installed on Apple devices. The platform data is stored locally on the device and synchronized between other user's devices using iCloud technology.

The ability to read, modify and write data to local storage can be requested by any third-party apps available in the AppStore.

The platform has a vast number of health data types (more than 160) and detailed documentation, providing easy integration with third-party apps. Most of the popular apps in the AppStore that allow you to monitor your health have implemented the HealthKit data synchronization feature.

Apple Health includes ResearchKit and CareKit frameworks, which provide researchers with the ability to build a ready-made health tracking and assessment application based on off-the-shelf modules. However, you still need to be a Swift or Objective C developer to use them.

Despite its great benefits, the main drawback of Apple Health is that it is isolated within the Apple ecosystem. Data from the platform can only be managed directly through the mobile app. The mobile application can interact with HealthKit only if it is implemented on the iOS platform. The lack of access to data

via open API also means that it is impossible to retrieve data on the Android operating system, which significantly narrows the range of users who can interact with the product implemented on this platform.

5.2. Google Fit

Google Fit⁴ was developed by Google in 2014 and is still being maintained and developed today.

The central part of the platform is a web service that provides a single set of APIs for data management on the platform. Platform data is stored remotely on Google Cloud servers and can be synchronized locally on the device.

It has its mobile app both in Google Play and AppStore, allowing the user to interact directly with the Google Fit by managing a limited set of health data types (about 30 types in total) available in the application.

For third-party developers, it is possible to manage user data from any device and application via the open API. A third-party service must request the appropriate permissions from the user through their Google account to access user data. Connecting to the platform is relatively easy by implementing the necessary API requests.

However, despite the flexibility of interaction with the platform, the number of health data types tracked is too small. In addition, the platform does not allow you to create your data types, which makes it impossible to use Google Fit as a universal health tracking platform.

5.3. Microsoft HealthVault

Microsoft HealthVault⁵ is a project developed by Microsoft in 2007 but closed in 2019.

In terms of functionality, the platform had a relatively extensive set of advantages. There was an application in the AppStore, as well as in Google Play. In addition, the user could access the service through the native web interface. The data was stored on the Microsoft Cloud service.

For third-party developers, the possibility to connect to the platform existed, but now it is difficult to identify if it was easy to implement since the documentation on the project is archived by the company. However, there is a freely available SDK for iOS and Android that implements basic requests to the platform.

It was also possible to access the platform through an API, which allowed researchers to receive data from users directly without creating a separate web service.

⁴ <https://www.google.ru/fit/>

⁵ https://en.wikipedia.org/wiki/Microsoft_HealthVault

The number and types of parameters in the project were quite extensive and allowed to keep most types of human health data.

However, despite its flexible data management capabilities, the platform lacked any possibility for data sharing and any feedback on the patient's health status. This resulted in users not getting any practical benefit from using the platform, resulting in Microsoft shutting down the project in 2019 due to a competitive disadvantage [40].

5.4. HealthBox

HealthBox⁶ – is an open-source project from independent developer “VOLT” published in 2020.

This project is not a finished product that can be downloaded from the AppStore or Google Play or even opened in a browser. However, its goal coincides very well with the primary goal of the smart healthcare platform, which is to centralize health data from different sources.

The developer of this project proposes a framework for a modular, centralized, and secure web service architecture that the user can use as-is or modify and then deploy as a Python-based web service to any device that allows it.

The apparent disadvantage of the project is its lack of popularity and the lack of services that can integrate with it. At this stage, users are offered to create their adapters, which will transmit data to this service from other applications. However, this project was launched relatively recently, and its development is still in progress, so this technology may find mass practical application in the future.

5.5. Open mHealth

Open mHealth⁷ – is an open-source project from independent developers at Open mHealth, founded in 2011. Unfortunately, according to the information on the project's website, we can conclude that its development was discontinued in 2019. Despite this, this project is an example of the approach to building a Smart Healthcare platform.

This project, like HealthBox, is not a finished product and represents the architecture for creating a web service that allows you to collect and process medical data from different sources.

Although the project is developed by independent developers, during its existence, it had nine use-cases. The authors presented an approach to share blood sugar data between the patient and the attending physician with the integration of data from eight other services [33]. They also provided a mechanism for shar-

⁶ <https://v0lttech.com/healthbox.php>

⁷ <https://www.openmhealth.org/>

ing and analyzing PTSD cases patient's data with integration from five other services [5, 32].

The main difference between Open mHealth and HealthBox is that Open mHealth has a much more elaborate data schema and the principle of interaction with the platform, allowing integration of data from different sources and process, visualize, visualize and send it to other services.

Despite the well-developed technical part, there are no cases of integration of this platform into mass projects. All of the use-cases are either targeted for software developers or a particular patient. However, the approach and architecture offered by this platform can be taken as a basis when working on a unified Smart Healthcare platform.

6. SMART HEALTHCARE PLATFORM

Based on the analysis of existing solutions, we can say that a successful Healthcare Platform must support the following requirements:

- (1) patients should receive practical benefit from the platform usage;
- (2) The platform should allow patients to share their data with family members or physicians securely;
- (3) the platform should provide an open API for developers to request permission and obtain access to the medical data;
- (4) the platform should be flexible in terms of health data types available for monitoring.

By looking at this list and comparing it with available platforms, we can see no solutions matching all the requirements. Lack of practical benefit for the patient, no data sharing, absence of open API, or flexibility of health data types is critical while developing Smart Healthcare platform. Because of that, there is no practical benefit from the platform either for users or for third-party companies. And while some of the platforms, like HealthVault and Open mHealth, are now abandoned because of that problem, more popular services like Apple Health and Google Fit are still growing. Still, they are only used by the users of their operating system, and those services can't be considered a universal platform.

Based on that, we propose a concept for the Smart Healthcare platform, supporting listed requirements.

6.1. Platform Concept

We propose to develop an open Smart Healthcare Platform architecture that would solve the problem of medical data exchange between the developers of mobile medical applications and between the users of such applications, providing transparent aggregation and sharing of medical data. This platform is supposed to be based on the principle of local storage and processing of personal data (utilizing mobile edge systems or using fog computing resources). Furthermore, we

should consider the possibility for the owners of medical data to share their data transparently with family members, physicians, and research institutions. Such a platform should allow developers of medical applications to significantly reduce development costs and simplify end-user access to various types of medical data.

As a user interaction model with this platform, we propose to use the principle of a two-way marketplace. Our solution should provide developers with the capabilities to create their services using our web service with Open API, predetermined data structure, SDK with all of the necessary requests already implemented, and developer interface. Companies can integrate with such a platform to solve their internal tasks or to provide their services. On the other hand, patients can receive services from different companies that do not depend on each other but provide their services in one place and in a format agreed upon by the system in advance.

6.2. Users of the platform

We can distinguish the following types of users for the smart healthcare applications that we should consider, providing the services of the Smart Healthcare Platform.

(1) *Patients* expect to get a wide range of medical services at an affordable price with personalized recommendations. In addition to getting a doctor's clinical diagnosis, they have the opportunity to gain more medical knowledge through a digital platform and connect with similar people for information such as disease symptoms, side effects, hospitalizations, medication information, clinical reports, and developmental scenarios. The patient is the primary source of information about their health through data generation on a mobile device.

(2) *Healthcare providers*. The vast amount of data collected at various stages of patient diagnosis and treatment helps healthcare providers get a realistic picture of the proposed course of treatment. Health system data includes lab results, clinical notes, medical imaging data, and sensor devices data. These data help improve public health surveillance and enable rapid response through practical analysis of disease patterns. In addition, data from handheld devices help doctors track medication use, keeping track of a patient's health status at any given time.

(3) *Clinical researchers*. The use of clinical data helps build predictive models for understanding biological processes and drug effects that contribute to high levels of efficacy in drug development. In addition, analyzing medical data from various sources helps clinical researchers measure drug development outcomes, even in small and rapid trials.

Although we have listed here all of the crucial stakeholders for our platform, they are not our pri-

Fig. 3. Proposed Smart Healthcare Platform architecture.

mary users. The primary users of the proposed platform should be developers that will provide services to the listed stakeholders through our platform. For developers, our platform should provide:

- Open API for direct communication with the platform;
- SDKs for development of mobile and web applications;
- management of patients' physiological data;
- management of measurement data of the patient's medical parameters, including CRUD operations;
- flexible direct data sharing capabilities with the trusted users through peer-to-peer communication;
- possibilities for anonymous medical data sharing in the cloud for supporting clinical researchers.

6.3. Platform Components

Given the above factors, we have proposed an architecture for the Smart Health Platform (see Fig.

3). We divide the interaction with the platform into three main parts.

First is the **device** part, which is accessible to direct users of the platform, such as patients, relatives, clinical researchers, and healthcare providers. On the device part, third-party developers can use the Smart Healthcare Platform SDK to implement their applications without having to deploy their servers.

Smart Healthcare Platform SDK will contain modules for different platforms with already implemented API calls for different use cases, providing developers with a convenient way to design data structure and implement data synchronization in their application.

This approach enables sharing the data inside the platform between different apps and devices using standardized protocols and data structures.

It provides developers with the ability to create applications for medical data management, monitoring, and analysis for patients, their relatives, clinical researchers, and healthcare providers.

Also, we propose to provide a **native or a web application** as a tool for monitoring and management all of the user's medical data aggregated from third-party applications and provide or revoke data access rights for those applications.

The platform's **backend** provides an Open API and Developer API/Web Interface for third-party applications. Backend is responsible for managing data storage and processing, access rights, and third-party applications. Applications distributed on the platform can request access to the users' data on the platform through dedicated APIs.

7. CONCLUSIONS

As part of this work, we analyzed existing approaches in "Smart Healthcare", their effectiveness in solving their tasks, and the technologies used to monitor and treat patients.

The results of our analysis show that the field of Smart Healthcare is currently in rapid growth. The technologies of mobile medicine, digital twins, and the Internet of Things can significantly improve monitoring of a person's health and positively influence their therapy.

However, research in these fields is still insufficient in assessing the effectiveness of these technologies in the long-term periods and considering complications of their mass integration in healthcare institutions. Therefore, the creation and integration of such technologies must be assessed for their practical and economic feasibility.

There are more and more mobile health devices, applications, and web services each year. However, the lack of standards and absence of a single platform for structuring medical services complicates integrating products in the healthcare field.

To systematize and form a unified approach to working with medical information, we proposed a Smart Healthcare Platform concept. In the future, we plan to refine the concept of the Smart Healthcare Platform, define the requirements for such a platform and develop an architecture that would allow us to create a flexible, secure, and reliable platform capable of adapting to the needs of a particular task.

ACKNOWLEDGMENTS

Sections 3, 5 of the study was carried out with the financial support of the Russian Foundation for Basic Research and Chelyabinsk Oblast in the framework of scientific project no. 20-47-740005, Sections 2, 4, 6 were carried out with the financial support of the Ministry of Science and Higher Education of the Russian Federation (state task FENU-2020-0022).

REFERENCES

1. Ahmed, M.N., Toor, A.S., O'Neil, K., et al., Cognitive computing and the future of health care cognitive computing and the future of healthcare: the cognitive power of IBM Watson has the potential to transform global personalized medicine, *IEEE Pulse*, 2017, vol. 8, no. 3, pp. 4–9.
2. Albahri, O.S., Albahri, A.S., Mohammed, K.I., et al., Systematic review of real-time remote health monitoring system in triage and priority-based sensor technology: taxonomy, open challenges, motivation and recommendations, *J. Med. Syst.*, 2018, vol. 42, no. 5.
3. Bot, B.M., Suver, C., Neto, E.C., et al., The mPower study, Parkinson disease mobile data collected using ResearchKit, *Sci. Data*, 2016, vol. 3, p. 160011.
4. Carozzi, F., Urban density and Covid-19, *CEP Discussion Pap.*, London School of Economics and Political Science, Centre for Economic Performance, 2020, no. 1711.
5. Chen, C., Haddad, D., Selsky, J., et al., Making sense of mobile health data: an open architecture to improve individual- and population-level health, *J. Med. Internet Res.*, 2012, vol. 14, no. 4, p. e2152.
6. Chen, M., Hao, Y., Hwang, K., et al., Disease prediction by machine learning over big data from healthcare communities, *IEEE Access*, 2017, vol. 5, pp. 8869–8879.
7. Farahani, B., Firouzi, F., Chang, V., et al., Towards fogdriven IoT eHealth: promises and challenges of IoT in medicine and healthcare, *Future Gener. Comput. Syst.*, 2018, vol. 78, pp. 659–676.
8. Free, C., Phillips, G., Watson, L., et al., The effectiveness of mobile-health technologies to improve health care service delivery processes: a systematic review and meta-analysis, *PLoS Med.*, 2013, vol. 10, no. 1, p. e1001363.
9. Frühlich, H., Balling, R., Beerenwinkel, N., et al., From hype to reality: data science enabling personalized medicine, *BMC Med.*, 2018, vol. 16, no. 1, p. 150.
10. Group T.J.D.R.F.C.G.M.S., Continuous glucose monitoring and intensive treatment of type 1 diabetes, *New Engl. J. Med.*, 2008, vol. 359, no. 14, pp. 1464–1476.
11. Jardine, J., Fisher, J., and Carrick, B., Apple's ResearchKit: smart data collection for the smartphone era?, *J. R. Soc. Med.*, 2015, vol. 108, no. 8, pp. 294–296.
12. Joyner, M.J. and Paneth, N., Seven questions for personalized medicine, *J. Am. Med. Assoc.*, 2015, vol. 314, no. 10, pp. 999–1000.
13. Kritzinger, W., Karner, M., Traar, G., et al., Digital twin in manufacturing: a categorical literature review and classification, *IFAC-PapersOnLine*, 2018, vol. 51, no. 11, pp. 1016–1022.
14. Li, H. and Ge, J., Cardiovascular diseases in China: current status and future perspectives, *IJC Heart Vascu-lature*, 2015, vol. 6, pp. 25–31.
15. Martin, J.L., Varilly, H., Cohn, J., et al., Preface: technologies for a smarter planet, *IBM J. Res. Dev.*, 2010, vol. 54, no. 4.
16. Mastoi, Q.U.A., Wah, T.Y., Raj, R.G., et al., A novel cost-efficient framework for critical heartbeat task

- scheduling using the Internet of medical things in a fog cloud system, *Sensors (Switzerland)*, 2020, vol. 20, no. 2.
17. Meng, L., Miao, C., and Leung, C., Towards online and personalized daily activity recognition, habit modeling, and anomaly detection for the solitary elderly through unobtrusive sensing, *Multimedia Tools Appl.*, 2017, vol. 76, no. 8, pp. 10779–10799.
 18. PD U. N.-D. of E. and S. A., 2013 undefined World population ageing 2013.
 19. Piron, L., Turolla, A., Agostini, M., et al., Exercises for paretic upper limb after stroke: a combined virtualreality and telemedicine approach, *J. Rehabil. Med.*, 2009, vol. 41, no. 12, pp. 1016–1020.
 20. Qudah, B. and Luetsch, K., The influence of mobile health applications on patient – healthcare provider relationships: a systematic, narrative review, *Patient Educ. Couns.*, 2019, vol. 102, no. 6, pp. 1080–1089.
 21. Rudner, J., McDougall, C., Sailam, V., et al., Interrogation of patient smartphone activity tracker to assist arrhythmia management, *Ann. Emerg. Med.*, 2016, vol. 68, no. 3, pp. S21–S25.
 22. Sadek, R.M., Mohammed, S.A., Abunbehan, A.R.K., et al., Parkinson’s disease prediction using artificial neural network, *Proc. 8th Latin American Conf. on Bio-medical Engineering and 42nd National Conf. on Bio-medical Engineering*, Cancún, 2019, pp. 1060–1065.
 23. Sardi, L., Idri, A., and Fernández-Alemán, J.L., A systematic review of gamification in e-Health, *J. Biomed. Inf.*, 2017, vol. 71, pp. 31–48.
 24. Snyderman, R., Personalized health care: from theory to practice, *Biotechnol. J.*, 2012, vol. 7, no. 8, pp. 973–979.
 25. Steinhubl, S.R., Muse, E.D., Topol, E.J., et al., The emerging field of mobile health, *Sci. Transl. Med.*, 2015, vol. 7, no. 283, pp. 283rv3–283rv3.
 26. Tian, S., Yang, W., le Grange, J.M., et al., Smart healthcare: making medical care more intelligent, *Global Health J.*, 2019, vol. 3, no. 3, pp. 62–65.
 27. Voigt, I., Inojosa, H., Dillenseger, A., et al., Digital twins for multiple sclerosis, *Front. Immunol.*, 2021, vol. 12, p. 1556.
 28. Wang, S., Parsons, M., Stone-McLean, J., et al., Augmented reality as a telemedicine platform for remote procedural training, *Sensors*, 2017, vol. 17, no. 10, p. 2294.
 29. Yang, W., Dall, T.M., Halder, P., et al., Economic costs of diabetes in the U.S. in 2012, *Diabetes Care*, 2013, vol. 36, no. 4, pp. 1033–1046.
 30. Zheng, Y.L., Ding, X.R., Poon, C.C.Y., et al., Unobtrusive sensing and wearable devices for health informatics, *IEEE Trans. Biomed. Eng.*, 2014, vol. 61, no. 5, pp. 1538–1554.
 31. Wearable device for blood glucose level automatic diagnostics and correction in diabetic blood was created. iCover.ru company blog. <https://habr.com/ru/company/icover/blog/392085/>. Cited 15.10.2020.
 32. Case study: Post-Traumatic Stress (PTSD) – Open mHealth. <https://www.openmhealth.org/features/case-studies/case-study-post-traumatic-stress-ptsd/>. Cited 28.04.2021.
 33. Case study: Type 1 diabetes – Open mHealth. <https://www.openmhealth.org/features/case-studies/case-study-type-1-diabetes/>. Cited 28.04.2021.
 34. ELPP 2016: Big Data for Healthcare. <http://scet.berkeley.edu/wp-content/uploads/Big-Data-for-Healthcare-Report-ELPP-2016.pdf>. Cited 14.10.2020.
 35. Healthcare IT Market – Global Forecast to 2024 | By Product & End User | MarketsandMarkets. <https://www.marketsandmarkets.com/Market-Reports/healthcare-it-252.html>. Cited 14.10.2020.
 36. Healthcare IT Market: Healthcare Information Technology Market Trends & Global Forecast (2010–2015): MarketsandMarkets. <https://www.marketsandmarkets.com/Market-Reports/healthcare-information-technology-market-136.html>. Cited 14.10.2020.
 37. Privacy-Preserving Contact Tracing – Apple and Google. <https://covid19.apple.com/contacttracing>. Cited 10.11.2020.
 38. ResearchKit – ResearchKit & CareKit. <https://www.researchandcare.org/researchkit/>. Cited 15.10.2020.
 39. Taking an ECG with the ECG app on Apple Watch Series 4, Series 5, or Series 6 – Apple Support. <https://support.apple.com/en-us/HT208955>. Cited 14.10.2020.
 40. What The Failure of Microsoft’s HealthVault Means for the Future of EHRs. <https://hitconsultant.net/2019/04/19/what-the-failure-of-microsofts-healthvault-means-for-the-future-ofehrs/>. Cited 28.04.2021.
 41. Alaasam, A.B., Radchenko, G., Tchernykh, A., et al., Analytic study of containerizing stateful stream processing as microservice to support digital twins in fog computing, *Progr. Comput. Software*, 2020, vol. 46, pp. 511–525. <https://doi.org/10.1134/S0361768820080083>
 42. Voevodin, V.V. and Popova, N.N., Infrastructure of supercomputing technologies, *Progr. Comput. Software*, 2019, vol. 45, pp. 89–95. <https://doi.org/10.1134/S0361768819030071>