Mobile Cyber-Physical System for Monitoring the Health of Patients with Cardiovascular Diseases

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Abstract

Currently, the successfully developed and implemented mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases is relevant. The conducted review of known cyber-physical systems for monitoring the health of patients with cardiovascular diseases showed that there are currently a large number of different solutions, but some of them are expensive, some of them are not mobile, some of them require the intervention of a specialist for operation and interpretation of indicators. Therefore, the purpose of this study is to develop a method and a mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases. The paper developed the rules and method for monitoring the health of patients with cardiovascular diseases, which ensure: every minute and every five minutes' formation of a set of indicators of the user's health status, analysis of indicators using the developed rules and issuance of a notification to the user about the risk or issuance of a notification to the user about risk with sending data about the existing risk to the user's family doctor and/or family member. The architecture of the mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases is based on the developed method and rules for monitoring the health of patients with cardiovascular diseases. The proposed mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases will help many cardiovascular patients to monitor the health of their heart, and will also help these people to receive emergency help in the event of a serious threat to their life and health.

Keywords

Mobile cyber-physical system, monitoring the health patients, patients with cardiovascular diseases, sensors for measuring the heart rate, sensors for measuring the blood pressure.

1. Introduction

Cardiovascular diseases are the leading causes of death and one of the main factors of disability worldwide. Such conclusions are obtained from the Global Burden of Disease study for 2019 [1].

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The burden of cardiovascular disease has continued to rise for decades in almost all low- and middle-income countries. Also alarming is the fact that the age-standardized rate of cardiovascular disease has begun to rise in some high-income countries, where it had previously been declining. Cases of CVD have nearly doubled from 271 million in 1990 to 523 million in 2019, and deaths from CVD have increased steadily from 12.1 million in 1990 to 18.6 million in 2019 [1].

In Ukraine, cardiovascular diseases are the main cause of population mortality. According to this indicator, Ukraine remains one of the world leaders. According to the data of the ranking compiled on the basis of the number of deaths of the population in Ukraine, the most frequent causes are: 1) cardiovascular diseases (64.3%); 2) neoplasms (14.1%); 3) diseases of digestive organs (4.3%); 4) neurological disorders (3.1%); 5) self-harm and interpersonal violence (2.7 %) [1].

Cardiovascular diseases that lead to fatal consequences for both men and women include arrhythmia and hypertension. Cardiac arrhythmias are a group of disorders of heart activity associated with disorders of the rhythm, sequence, and strength of heart muscle contractions. The main forms of cardiac arrhythmias are acceleration of heart contractions over 100 beats per minute (tachycardia), slowing of heart contractions below 60 beats/minute (bradycardia) [2-4].

Arterial hypertension is a chronic disease, during which the main diagnostic feature is a persistent increase in hydraulic pressure in the arterial vessels of a large circle of blood circulation. Two indicators are used to measure blood pressure: systolic and diastolic pressure, depending on whether the heart muscle contracts between beats (systole) or relaxes (diastole). Normal blood pressure at rest is in the range of 100-139 mm Hg. Art. for systolic pressure (upper value) and 60-89 mm Hg. Art. for diastolic pressure (lower value). Blood pressure is considered high if it is constantly kept at the level of 140/90 mm Hg. Art. or higher [5-7].

Another cardiovascular disease that causes discomfort to a person is arterial hypotension. Arterial hypotension is a condition determined by a decrease in systolic blood pressure below 100 mm Hg, diastolic blood pressure below 60 mm Hg. Art. [5, 6].

Since cardiovascular diseases are chronic diseases of the circulatory system, they should be detected and prevented in real time to minimize harm to human health. Vital signs of patients with cardiovascular disease should be monitored to detect abnormal events before any critical conditions that could lead to death occur. A pulse oximeter or tonometer is used to assess an irregular heartbeat (arrhythmia) at home. A tonometer is used to determine high/low blood pressure at home. Diagnosis of cardiovascular disorders requires constant long-term monitoring of individuals. That is, a person must have these devices with him all the time to measure pulse or blood pressure, and he must do it deliberately and constantly. In addition, a person must know the reference values of heart rate and blood pressure in order to correctly diagnose the existing problem. Given the uncertainty surrounding where and when immediate diagnosis and treatment may be needed, the only practical solution is continuous monitoring of heart rate and blood pressure. Tools for monitoring health-related parameters significantly facilitate patient care and allow people to identify problems that lead to better management of their own health [8].

Considering the fact that there is currently a tendency to automate the field of medicine, which increases the efficiency of using modern medical resources [9-12], as well as considering the importance of constant self-diagnosis and monitoring of the health of patients with cardiovascular diseases, it is necessary to automate as much as possible and make it permanent such measurement and monitoring. Currently, medical cyber-physical systems are often used to solve such problems - unique cyber-physical systems that combine built-in software control devices, network capabilities and complex physiological dynamics of patients in the modern medical field [13-15]. In this case, a mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases in the form of a bracelet that a person can wear constantly, which will constantly monitor a person's heart rate and blood pressure in real time and will notify a person of heart failure or deviation from the normal pressure of a person as soon as it notices such deviations, can come to a person's aid for automation and consistency of heart rate and blood pressure measurements. So, currently, the successfully developed and implemented mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases is relevant task.

2. Literature review

Let's review the known cyber-physical systems for monitoring the health of patients with cardiovascular diseases.

The paper [16] proposed the cloud-based cyber-physical system for identifying the Coronary Heart Disease risk level at an early stage in real time using adaptive neuro fuzzy inference system.

The paper [17] proposed the general framework for three heart care sensors (ECG (Electrocardiogram) sensor, PCG (Phonocardiogram) sensor and Lung sound sensor), which is connected to server that performed the monitoring of heart health and forecasting the cardiovascular diseases.

The paper [18] proposed the end-to-end cyber-physical system e-Nanoflex that support nanostructure based flexible sensors for monitoring the variety of conditions such as respiration air flow, body temperature, oxygen consumption, pulse oximetry, bioelectric signals, neural activity, muscle activity, etc.

Paper [19] proposed Smart Cardiovascular Disease Detection System (SCDDS) based on Electrocardiogram for detecting the heart disease in advance.

Paper [20] proposed the IoT enabled, cloud-centric solution for remote monitoring of ECG, which enables the visualization and analyzed the ECG data over the cloud server, and data is shared with cardiologist for examination.

The review [21] conducted a literature search on measurement of blood pressure using only a smartphone, and analyzed the validation of the methods against reference measurements of blood pressure. The conclusion of authors – no established protocol for the validation of measuring technologies of blood pressure using only a smartphone.

Paper [22] analyzed the publications on the wearable and portable systems for continuous monitoring the health of patients with cardiovascular diseases.

The paper [23] proposed the framework for early detection of cardiovascular events based on the deep learning architecture in IoT environments, that have better performance.

The paper [24] proposed the computer vision system, which remotely measures the blood pressure using a digital camera on the basis of the optical properties of photoplethysmographic signals in the forehead and calculates blood pressure measures based on specific formulas.

Paper [25] proposed the smart stethoscope on the basis of the technology of multimodal physiological signal measurement for personal cardiovascular health monitoring in the shape of the compact computer mouse.

The conducted review of known cyber-physical systems for monitoring the health of patients with cardiovascular diseases showed that there are currently a large number of different solutions, but some of them are expensive, some of them are not mobile, some of them require the intervention of a specialist for operation and interpretation of indicators. Therefore, the purpose of this study is to develop a method and a mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases.

For development of the mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases, the following tasks should be solved: the rules for monitoring the health of patients with cardiovascular diseases were developed; the method for monitoring the health of patients with cardiovascular diseases was developed; the architecture of a mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases was designed.

3. Mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases

Let's develop the rules for monitoring the health of patients with cardiovascular diseases.

Rules for monitoring the health of patients with cardiovascular diseases:

1. if within 5 minutes the heart rate (indicators hr_i, hr_{i+1}, hr_{i+2}, hr_{i+3}, hr_{i+4} at the same time) is more than 100 beats per minute, then the user receives the message: "Tachycardia" and $j=j+1$
2. if within 5 minutes the heart rate (indicators hr_i, hr_{i+1}, hr_{i+2}, hr_{i+3}, hr_{i+4} at the same time) is less than 60 beats per minute, then the user receives the message: "Bradycardia" and $j=j+1$
3. if within 5 minutes the systolic pressure (indicators sp_i, sp_{i+1}, sp_{i+2}, sp_{i+3}, sp_{i+4} at the same time) is more than 140 mm Hg. Art., then the user receives the message: "Arterial hypertension" and $j=j+1$
4. if within 5 minutes the diastolic pressure (indicators dp_i, dp_{i+1}, dp_{i+2}, dp_{i+3}, dp_{i+4} at the same time) is more than 90 mm Hg. Art., then the user receives the message: "Arterial hypertension" and $j=j+1$
5. if within 5 minutes the systolic pressure (indicators sp_i, sp_{i+1}, sp_{i+2}, sp_{i+3}, sp_{i+4} at the same time) is less than 100 mm Hg. Art., then the user receives the message: "Arterial hypotension" and $j=j+1$
6. if within 5 minutes the diastolic pressure (indicators dp_i, dp_{i+1}, dp_{i+2}, dp_{i+3}, dp_{i+4} at the same time) is less than 60 mm Hg. Art., then the user receives the message: "Arterial hypotension" and $j=j+1$
7. if within 5 minutes the heart rate (indicators hr_i, hr_{i+1}, hr_{i+2}, hr_{i+3}, hr_{i+4} at the same time) is more than 150 beats per minute, and the user has not confirmed that he saw the message within 30 seconds about tachycardia, then the message "Tachycardia, critical indicators" together with the user's first and last name and geolocation is transmitted from the user's mobile phone to his family doctor and/or family member and $j=j+1$
8. if within 5 minutes the heart rate (indicators hr_i, hr_{i+1}, hr_{i+2}, hr_{i+3}, hr_{i+4} at the same time) is less than 45 beats per minute, and the user has not confirmed that he saw the message within 30 seconds about bradycardia, then the message "Bradycardia, critical indicators" together with the user's first and last name and geolocation is transmitted from the user's mobile phone to his family doctor and/or family member and $j=j+1$

9. if within 5 minutes the systolic pressure (indicators sp_i, sp_{i+1}, sp_{i+2}, sp_{i+3}, sp_{i+4} at the same time) is more than 180 mm Hg. Art., and the user has not confirmed within 30 seconds that he has seen a message about arterial hypertension, then the message "Arterial hypertension, critical indicators" together with the user's name and surname and geolocation is transmitted from the user's mobile phone to his family doctor and/or family member and $j=j+1$
10. if within 5 minutes the diastolic pressure (indicators dp_i, dp_{i+1}, dp_{i+2}, dp_{i+3}, dp_{i+4} at the same time) is more than 120 mm Hg. Art., and the user has not confirmed within 30 seconds that he has seen a message about arterial hypertension, then the message "Arterial hypertension, critical indicators" together with the user's name and surname and geolocation is transmitted from the user's mobile phone to his family doctor and/or family member and $j=j+1$
11. if within 5 minutes the systolic pressure (indicators sp_i, sp_{i+1}, sp_{i+2}, sp_{i+3}, sp_{i+4} at the same time) is less than 80 mm Hg. Art., and the user has not confirmed within 30 seconds that he saw a message about arterial hypotension, then the message "Arterial hypotension, critical indicators" together with the user's name and surname and geolocation is transmitted from the user's mobile phone to his family doctor and/or family member and $j=j+1$
12. if within 5 minutes the diastolic pressure (indicators dp_i, dp_{i+1}, dp_{i+2}, dp_{i+3}, dp_{i+4} at the same time) is less than 55 mm Hg. Art., and the user has not confirmed within 30 seconds that he saw a message about arterial hypotension, then the message "Arterial hypotension, critical indicators" together with the user's name and surname and geolocation is transmitted from the user's mobile phone to his family doctor and/or family member and $j=j+1$

Then *the method for monitoring the health of patients with cardiovascular diseases* consists of the following steps:

1. reset the counter of used rules: $j=0$
2. minute-by-minute formation of a set of indicators of the user's state of health (set *IUH*): heart rate (indicator *hr*), systolic pressure (indicator *sp*), diastolic pressure (indicator *dp*): $IUH=\{hr_i, sp_i, dp_i\}, i=1..\infty$
3. formation of a set of indicators of the user's health every 5 minutes (set *IUH5*): $IUH5=\{hr_i, sp_i, dp_i, hr_{i+1}, sp_{i+1}, dp_{i+1}, hr_{i+2}, sp_{i+2}, dp_{i+2}, hr_{i+3}, sp_{i+3}, dp_{i+3}, hr_{i+4}, sp_{i+4}, dp_{i+4}\}, i=1..\infty$
4. analysis of the set of indicators of the user's health every 5 minutes (set *IUH5*) – using each of the developed rules for monitoring the health of patients with cardiovascular diseases
5. if after the analysis $j=0$, then the user's condition is normal, and no action is taken, otherwise actions are taken (issuing a notification about the risk; or issuing a notification about the risk and sending the data to the family doctor and/or a member of the user's family) according to the triggered rule(s)

The developed rules and method for monitoring the health of patients with cardiovascular diseases ensure: every minute and every five minutes' formation of a set of indicators of the user's health status, analysis of indicators using the developed rules and issuance of a notification to the user about the risk or issuance of a notification to the user about risk with sending data about the existing risk to the user's family doctor and/or family member.

The architecture of the mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases is based on the developed method and rules for monitoring the health of patients with cardiovascular diseases.

The architecture of the mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases is presented in Figure 1.

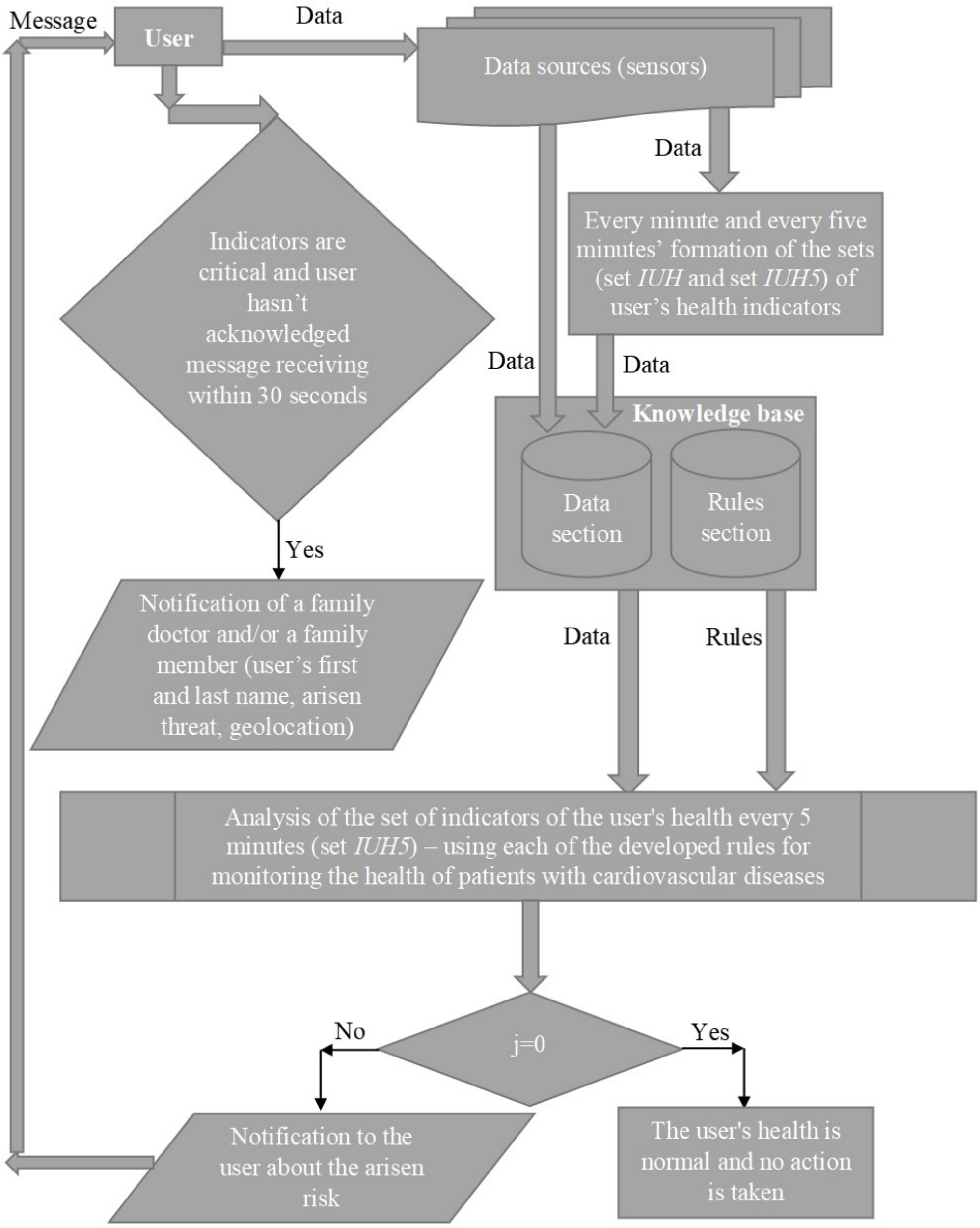

Figure 1: Architecture of the mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases

Mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases includes a set of sensors for measuring the necessary indicators - sensors for measuring heart rate and sensors for measuring blood pressure. Mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases is a bracelet in which these sensors are installed, as well as a specially developed mobile application on the user's smartphone. In the mobile application, when registering, the user indicates his first and last name, gives the application access to geolocation data, and notes the mobile phone numbers of people to whom the data should be transferred in the event of a serious threat to the life and health of the user (family doctor and/or member(s) the user's family). With the help of the bracelet, a set of indicators of the user's health is formed every minute and every five minutes, as well as the analysis of the indicators using the above developed rules for monitoring the health of patients with cardiovascular diseases. If the heart rate and/or blood pressure readings exceed the reference values (rules 1-6), the user receives a message on the smartphone in the mobile application about the corresponding risk according to the rule(s) that has been triggered. The user must confirm that he received the message within 30 seconds on the smartphone. If the heart rate and/or blood pressure readings are critical (rules 7-12) and the user has not confirmed the receipt of the relevant risk message on the smartphone within 30 seconds, the user data (name, surname and emerging threat) is transmitted along with geolocation to the phone of the family doctor and/or family member, so that they can quickly call an ambulance based on the provided geolocation.

4. Results & Discussion

Let's consider the functioning of the developed method for monitoring the health of patients with cardiovascular diseases and mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases.

For the first example, we will consider the use of the proposed mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases by a 73-year-old woman who is a patient of the outpatient clinic of family medicine in the Ozerna microdistrict (Khmelnytskyi) and who suffers from frequent attacks of tachycardia and arterial hypertension.

The woman was put on a bracelet with sensors mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases and the developed mobile application was installed on her smartphone. The family doctor helped the patient register in the mobile application – enter her first and last name, give the application access to geolocation data, and specify the mobile phone numbers of people to whom the data should be transferred in the event of a serious threat to the life and health of the user (the family doctor and the patient's son). After three days of wearing the bracelet, the family doctor and the patient's son received the message "Hypertension, critical indicators" on their phones, along with the patient's first and last name and her geolocation. The family doctor immediately called an ambulance at the indicated geolocation – the ambulance doctors found the patient unconscious in the yard of her house, the patient had a hypertensive crisis, the systolic pressure was 200 mm Hg. Art., diastolic pressure was 140 mm Hg. Art. In this case, the developed mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases helped to save the patient and prevent her stroke.

For the second example, we will consider the use of the proposed mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases by a 45-year-old man, who is also a patient of the outpatient clinic of family medicine in the Ozerna microdistrict (Khmelnytskyi) and who suffers from frequent attacks of bradycardia, which must be detected in time with for the purpose of timely use of the necessary medical drugs.

The man was put on a bracelet with sensors mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases and a developed mobile application was installed on a smartphone. The family doctor helped the patient register in the mobile application – enter his first and last name, give the application access to geolocation data, and specify the mobile phone numbers of people to whom the data should be transferred in the event of a serious threat to the life and health of the user (the family doctor and the patient's wife). During the next visit to the family doctor, the patient said that thanks to the bracelet, he has much easier attacks of bradycardia, because the bracelet informs him of the onset of an attack even before he feels significantly worse, and he immediately uses the medical drugs recommended by the doctor, so the attack can be stopped at its beginning. In this case, the developed mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases helps the patient in self-diagnosis and monitoring of his state of health and timely use of the necessary medical drugs in the event of a risk.

So, the proposed mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases will help many cardiovascular patients to monitor the health of their heart, and will also help these people to receive emergency help in the event of a serious threat to their life and health.

5. Conclusions

Currently, the successfully developed and implemented mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases is relevant.

The conducted review of known cyber-physical systems for monitoring the health of patients with cardiovascular diseases showed that there are currently a large number of different solutions, but some of them are expensive, some of them are not mobile, some of them require the intervention of a specialist for operation and interpretation of indicators. Therefore, the purpose of this study is to develop a method and a mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases For development of the mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases, the following tasks were solved: the rules for monitoring the health of patients with cardiovascular diseases were developed; the method for monitoring the health of patients with cardiovascular diseases was developed; the architecture of a mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases was designed.

The paper developed the rules and method for monitoring the health of patients with cardiovascular diseases, which ensure: every minute and every five minutes’ formation of a set of indicators of the user's health status, analysis of indicators using the developed rules and issuance of a notification to the user about the risk or issuance of a notification to the user about risk with sending data about the existing risk to the user's family doctor and/or family member.

The architecture of the mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases is based on the developed method and rules for monitoring the health of patients with cardiovascular diseases.

The proposed mobile cyber-physical system for monitoring the health of patients with cardiovascular diseases will help many cardiovascular patients to monitor the health of their heart, and will also help these people to receive emergency help in the event of a serious threat to their life and health.

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