A System for Hypertension Management Assistance Based on the Technologies of the Smart Spaces

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Abstract. Affecting up to 40% of the world's population, arterial hypertension results in high economic and social burden. Long-term treatment period along with the necessity of personal lifestyle changes lead to the low adherence to the treatment among the patients. As a consequence, the hypertension-related complications can be gradually developed between visits to the doctor, among them are heart attack, heart failures, strokes and even sudden cardiac death. In the proposed integrated approach, the mobile personal monitoring system, constructed on the principles of smart spaces, is used to address the problem of low adherence. Both continuous monitoring of the vital signs and the questionnaire-based regular health status audit are used for the assessment of the complication risk. Health parameters and evaluated risk markers are published in the semantic-driven information storage, and the personalized recommendation service, aimed at the increasing the adherence to the treatment among hypertensive patients, is constructed based on cooperation of distributed software agents.

Keywords: Mobile healthcare · Smart spaces · Hypertension management · Patient adherence

1 Introduction

Approximately 30–40% of the world's population suffers from increased arterial pressure (arterial hypertension). According to the World Health Organization report, arterial hypertension is the most essential preventable risk factor of premature death [1]. Prevention and treatment of arterial hypertension heavily rely on behaviour change, moreover, for the majority of patients, a substantial modification of their lifestyle has prime significance [2]. Therefore, the therapy is time-consuming and it demands a self-discipline from the patient. It is shown that in a six months period more than a third, and in a year more than a half of the patients, stop the appointed treatment, and about 10% of the patients forget to accept medicines daily [3,4]. Thus, there is a problem of low adherence of the hypertensive patients to prevention and treatment, i.e., of the readiness for strict observance of the instructions appointed by the doctor both at medicines

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intake and at the behaviour change (e.g., of the recommendations to intensify the physical activity, stick to a healthy eating plan, etc.)

The solution of this problem can be built on an integrated approach to hypertension management including the use of the background intellectual environment to supervise the patient by means of the systems of personal recommendations (intellectual assistants). Aforesaid personalized medicine systems are considered to be a promising way to open the adaptation opportunities of a human being and to increase the duration of his active life, and research and development initiatives in the area of personalized medicine are supported by governmental programs [5]. From the other hand, personalized medicine demands support of mobility of the patient, realization of complex collecting and the analysis of personal data and a context information, and also "smart" decisions on the basis of personalisation, a context, and recommendation systems [6].

This paper presents the architectural approach to the design of the hypertension management assistance system aimed at the increasing of the adherence to the treatment among hypertensive patients. In the proposed approach, health-related data are gathered from multiple sources and are stored in semantic-driven storage for the further construction of personalized recommendations. The remote patient is equipped with wearable electrocardiogram recorder and fitness wristband that transfer health-related data to the personal mobile device. Also, the patient provides the regular questionnare-based health log. History of past medical events, individual contraindications, etc., are received from the electronic health record (EHR). The system is composed from the set of communicating agents that provide the data and consume them to produce the recommendations. Thus, the proposed solution is significantly banks on the recent advances in mobile healthcare, smart environments and cloud computing. This approach leads to minimization of risk of complications due to improvement of prevention, early diagnostics, forecasting of development of the disease.

The paper is organized as follows. In the Sect. 2, an overview of the results of recent related studies is given. Section 3 describes the sources of the gathered data. Section 4 introduces the architecture of the hypertension management system and discusses the construction of the personalized recommendation service. Section 5 concludes the study.

2 Related Work

Due to the advances in wearable technology, continuous registration of the vital signs became possible, providing the opportunity of the biosignal processing either on the local hardware, or in the cloud. For this reason, the efforts of researches are directed to the adoption of health sensors in the healthcare services.

A number of electrocardiogram analysis algorithms are developed in our previous work within a CardiaCare project that is aimed at continuous monitoring of heart function in real-time and analyzing electrocardiograms on a smartphone [7–9]. Within the CardiaCare project the efforts are concentrated on timely detection of rhythm abnormalities. Despite the fact that the arrhythmias are harmless in general, they can pose serious threat of complications against chronic diseases such as hypertension or diabetes. Thus, continuous heart rhythm monitoring provides the possibility to detect the deterioration of heart function and even to save the life, and these results form the base of our current work.

This paper significantly utilizes the concept of smart healthcare service discussed by Korzun et al. [10] and follows the idea of the smart service construction as the result of knowledge reasoning over a shared information. The ontology for hypertension management proposed by Steichen et al. [11] was adapted for representing data statements and relationships in machine-processible form.

3 Health Data Sources for Recommendation Construction

Recommendations for the patient are constructed on the base of analysis of continuously or regularly registered vital signs and personal health log. During the monitoring, the electrocardiograms and physical activity data are recorded automatically. Also, the patient manually records the results of independent measurements of the blood pressure and logs drug intakes. This allows to evaluate the blood pressure variability depending on many factors (ECG parameters, drug schedule, day time, etc.) between visits to the clinic.

There are a lot of possible ECG parameters that are considered to be the cardiovascular risk markers. The following ECG parameters are monitored: (1) heart rhythm disturbances such as arterial fibrillation, premature ventricular contraction and others; (2) heart blocks; (3) heart rate; (4) P wave duration; (5) P wave amplitude; (6) P wave morphology, in particular, two-phase shape; (7) PQ interval duration; (8) QT dispersion; (9) Q width; (10) R amplitude; (11) S amplitude; (12) QRS width; (13) QT duration; (14) T wave amplitude; (15) T wave alternation; (16) T wave width and "T peak-to-end" parameter; (17) ST elevation; (18) ST decrease; (19) rhythm turbulence; (20) heart rate variability.

To increase the adherence, the mobile app provides a simplified questionnaire for the regular log of complaints (including experiencing headaches, chest pain, interruptions in work of heart or heartbeat, breathing difficulties, physical activity interruptions in connection with an illness, sleep disorders, proper taking the medications, etc.) and analysis of their connections with hypertension and drug treatment. At the whole, the log gives the life quality assessment that defines the adherence of the patient to the treatment plan.

The application allows the patient to send the alarm notification in the emergency case in order to timely address to the doctor and obtain the further guideline (e.g., call the ambulance or to take medications independently). The patient is able to attach the list of complaints to the alarm notification.

4 Hypertension Management System Architecture

In the proposed hypertension management assistance system, the smart spaces approach is applied to achieve the high system scalability in IoT environments.

From the one hand, the market of m-Health applications with health parameter monitoring experiences the explosive growth due to the progress of IoT technology and the advances in wearable medical devices development. For this reason, the developed system should provide a way of facile integration of the new sensor hardware. From the other hand, the development of the proposed service should support effective integration of the existing healthcare services provided by hospital information systems, in particular, the electronic health records, and to enhance them up to the level of smart services [12]. Therefore, the designed smart space-based system architecture of personalized assistance services should consider the system composed from the many components, focusing on component functionality reuse instead of reinvention.

In [10], the reference scenarios of personalized assistance and their smart space-based implementations were discussed on the example of the service aimed at the increasing the efficiency of the first aid in medical emergencies. Following the same approach, we construct the smart services for hypertensive patients.

In general, a smart space provides means for many networked devices to participate by cooperatively sharing information and other resources. Each device hosts so-called knowledge processor (KP), which acts as a software agent interacting with users, sensor equipment, and other KPs. The data produced by one KP can be shared with other KPs by means of semantic information broker (SIB). The latter provides storage for shared information collection and querying mechanism. SIB and its storage can be considered as a semantic knowledge base over multiple and dynamic data sources, similarly as it happens in the Semantic Web. That is, the knowledge base and its KPs form a computing system environment that we call a smart space. According to this definition of a smart space, we propose the architecture of smart system for hypertension management assistance, as it is shown in Fig. 1.

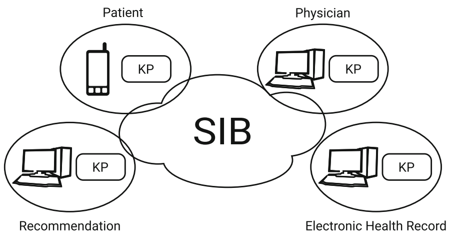

Fig. 1. Multi-agent smart hypertension management assistance system.

In the proposed system, the ontology-oriented approach is adopted for representation of the shared information in machine-processible manner as a semantic network that relates a variety of heterogeneous data sources and their consumers. Data sources and consumers are represented by KPs as well as some KPs are responsible for reasoning over the data.

Consider a part of the scenario of hypertension management in remote patient. The patient is equipped with the personal mobile device running the

KP and portable sensor devices. The mobile device has positioning capabilities, therefore, the location of the patient is also known.

The interaction of KPs resulting in service construction is shown in Fig. 2. A service is constructed due to cooperative activity of KPs participating in the same smart space. The Patient KP shares the location, questionnaire answers and health data (along with the results of its processing) in the smart space. The patient is able to use the "panic button" also. The Electronic Health Record KP updates the EHR and also publishes some data in the SIB, e.g. contraindications. Recommendation KP integrates the current health status and the data from EHR and produces recommendations to the patient.

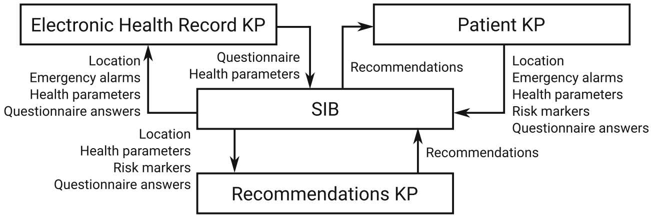

Fig. 2. Construction of the service as a cooperative activity of knowledge processors

The discussed above smart space-based hypertension assistance service provides a high level of scalability without the need of redesign of the system at whole in case of modification of individual components.

5 Conclusion

This paper proposed the system for decreasing of the hypertension-related risk and addressing the low adherence problem based on concepts of m-Health and smart spaces. The multi-agent architecture of the offered system was described and construction of the personalized digital assistance services for remote hypertensive patients was discussed.

According to the proposed approach, the prototype of the system was implemented based on the Smart-M3 platform. The mobile applications that are intended to monitor hypertensive and prehypertensive patients, to assess the risks and to track their adherence to the treatment were developed for Android OS and Sailfish OS.

For the forthcoming analysis of advantages of the approach up to the 300 hypertensive patients were selected for control group on the base of Petrozavodsk Hospital of Emergency Care. The examination included the natural history analysis, the assessment of usual risk factors, identification of subclinical asymptomatic organ damage (ultrasound scanning of carotid arteries, microalbuminuria, left ventricle hypertrophy, coronary calcium index), identification of cardiovascular or renal diseases, blood pressure variability between visits, adherence to treatment according to existing indexes and questionnaires.

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