Smartwatch-based wellbeing monitoring system for the elderly

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Abstract — **In this paper a health monitoring system based on the off the shelf smartwatch and mobile phone is described. The system enables remote monitoring of an elderly person or a patient by measuring the sensor data, available on the smartwatch. Data is sent to the mobile phone, processed, and then sent further to the server application. The caregiver is able to see the measured data like a heart rate or current activity at any time, to send a notification to the patient, or to check the statistics or the history of measured values. In this paper, we describe the implementation and functionalities of such a system and discuss the advantages and shortcomings.**

I. INTRODUCTION

Pervasive health can be defined as a higher quality healthcare given to anyone, anytime, anywhere. Demographic population and social changes, the ever-increasing healthcare system costs and the increase of the elderly population in developed countries has led to significant problems in the healthcare systems. Therefore, changes in both strategy and organization are needed, and pervasive and personalized healthcare represents important and positive steps in solving these problems. Health state monitoring of the individual person enables us to assess and predict a possibility for the disease development, based on genetic or other factors, and thus enables the caretaker to act preemptively. This will also enable a caregiver to provide more efficient, less-costly, quality medical care.

The possibility for application of personalized and pervasive health systems is the largest in the elderly population. Other motives for elderly health monitoring system research are the significant worldwide increase of an aging population. In fact, according to the World Health Organization (WHO), the world's elderly population (defined as people aged 60 and older) has increased drastically in the past decades and will reach about 2 billion in 2050, and in Europe the elderly population above 65 years of age is foreseen to rise to 30% in 2060 [6].

The elderly people have specific health issues that must be considered. A significant proportion of the elderly population suffers or may suffer with higher probability from age-related conditions such as Parkinson's disease, diabetes, cardiovascular disease, Alzheimer's disease, different chronic diseases, and limitations in physical functions.

Technologies that are used in pervasive and personalized health can significantly improve the quality of life of the elderly, decrease the time caretakers need to spend with them, and therefore decrease the cost of the medical care for the elderly population in general. This means that these technologies positively impact not only the elderly population, but also their families, caretakers, doctors, nurses, and the society in general.

Sensor-based monitoring systems promise to improve and prolong independent living of elderly people. Different solutions are already available on the market, which use mobile phones and wireless sensors installed in a home to monitor the well-being of people. These systems can actively monitor, model and promote healthy behavior, and on the other side, provide caregivers with statistics or trigger real-time notifications when an unhealthy or risky situation is detected. Furthermore, long-term monitoring can help detect or support the early diagnosis of neurodegenerative diseases.

Smartwatches have the potential to support health in everyday living by enabling self-monitoring of personal activities; obtaining feedback based on activity measures; and supporting bi-directional communication with health care providers and family members. However, smartwatches are emerging technology and research with these devices is at the early stage. Consumers' intention to accept smartwatch is subject of several research articles [2].

A systematic review of smartwatch studies that engaged people in their use by searching scientific databases is described in [3] and returned only seventeen studies. Most studies employed the use of consumer-grade smartwatches (14/17, 82%). Patient-related studies focused on activity monitoring, heart rate monitoring, speech therapy adherence, diabetes self-management, and detection of seizures, tremors, scratching, etc.

The main problem we address in this paper is remote wellbeing and health monitoring of the elderly people by using off the shelf hardware (smart watch and mobile phone). We research:

- if and how this system can be implemented,
- what are the advantages and disadvantages of such a system,
- what type of data can be gathered or measured,
- and whether the system is more practical than similar solutions proposed in [4], [5], [6], [7], [8].

II. RELATED WORK

The development of the proposed system is largely enabled by the recent smartwatch breakthroughs. Nowadays smartwatch batteries can last from couple of days to a whole month depending on the display type. Watch manufacturers have recently implemented or opened access to low-level application programming interfaces (API) which enable developers to access different sensors present on the smartwatches. The market adaptation of wearable devices, watches or other fitness trackers is growing each year. All these devices gather raw data and track our activities, and it is only the matter of time when all these data will be integrated in one overall system that will be in charge for monitoring our health.

In the paper [10] authors illustrate such a system by using two off-the-shelf smartwatches for activity recognition. However, they do not propose a system that can at the same time be used for overall monitoring of the persons health state. The BeWell application described in [4] and PPCare described in [5] are systems that use a mobile phone to monitor, model and promote well-being. They detect physical activity, social interaction and sleep patterns, but do not include smartwatch nor implement bi-directional communication with health care providers. The general characterization of activities and sensing infrastructure is described in [1].

There are several papers that describe remote health monitoring systems. Paper [11] gives in detail overview of remote health monitoring systems in general, and gives guidelines on implementing system and lists ongoing issues and challenges.

In [6] authors describe TeleCARE system intended to be used in the treatment of patients with cardiovascular diseases. The system uses custom made “medication container” for data gathering. Authors mention that their system supports wearable integration, but have not actually implemented or verified any of the wearable devices.

In [7] authors propose another system, but the focus of the research is on the implementation and verification of the overall system architecture. Finally, the system that uses users mobile phone for data gathering is described in [8]. The system used set of different sensors that patient needs to wear on different parts of his body, as well as Bluetooth device that is strapped on his waist.

III. IMPLEMENTATION AND EVALUATION

The system described in this paper called **Health Assistant** enables self-monitoring of personal activity, health state, and supports bi-directional communication with healthcare providers.

Typical data model of a system for remote health monitoring has three independent steps. The first is gathering and preprocessing of raw data from smartwatch sensors (or some other sensors). The second step is processing of the acquired data, usually on the server, to get information in context. The last step would be application of artificial intelligence methods to recognize complex contexts or predict future behavior. Based on the acquired information, we decide on the actions that we take to ensure high quality medical care. In this paper, we describe a system that can acquire raw data, process it into useful statistics, show it on the mobile phone or web application, and enable a caretaker to monitor and act by sending notifications to the patient.

When the system and the smartwatch application were designed we had in mind a research done in [9] that describes human computer interaction with a smartwatch and [2] that describes factors that influence consumer to accept the smartwatch. In the original paper, the topic was smart home control, but the described methods apply to health monitoring as well. The simplified **architecture of the system** is shown on Figure 1. The system consists of a Tizen application, an Android application, and a Web application.

The **Tizen application** runs on the smartwatch which is used as a sensor device. Samsung Gear S3 was used for implementing and testing the proposed system. Application was implemented in Tizen software development kit (SDK) as a Tizen wearable web application in standard web technologies.

The application can show currently measured sensor values, like current hearth rate, activity, or amount of light measured. The smartwatch API can detect three different activity states: walking, driving, and stationary. The application can also receive notifications from doctors or caregivers and send responses. For example, a caretaker can send a reminder “take medicine” and ask for the confirmation from the patient.

The smartwatch sends all measured data to the Android application via Bluetooth. All Tizen smartwatches are not intended to run independently from the mobile phone and are optimized to have persistent connection which is used for the data exchange. In case of connection loss, the watch can save the data in its local storage and then, when the connection is reestablished, send the data to mobile phone.

The Android application is sort of a data hub that collects the data sent from the smartwatch. It can be scaled to receive data from the additional sensors other than the ones we find on the smartwatch. Data is processed and then synchronized with the server. The application communicates with the server over HTTP protocol that is implemented with the *Volley Android library.*

The Android application can also show the measurement history and notification history as shown on the Fig. 2.

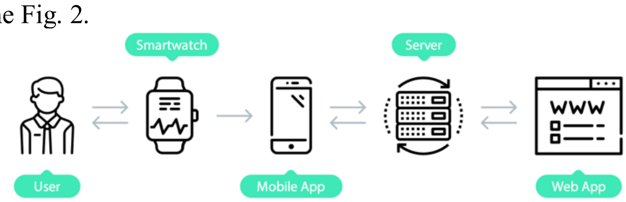

Figure 1. A general architecture of the system

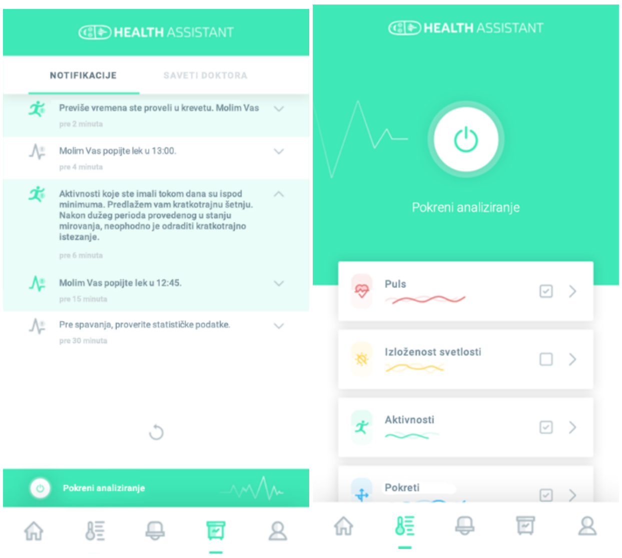

Figure 1 – Android Application User Interface

The request for the data measurement (i.e. hearth rate, activity etc.), can be sent remotely, from the mobile or web application. Although, there is a concern weather a patient should be allowed to remotely start or stop the measurements on the mobile phone, as a potential conflict can arise. For example, caregiver can start measurement from the web application, and the patient can disable it on the phone. We decided to keep this option for testing purposes as it is also shown on Fig. 2, but this can easily be removed.

All administration functionalities like adding new caregivers or setting measurement time period per patient can be done within **PHP web application**. It can further be used to review the notification history or to review the daily, weekly or monthly statistics of the sensors measurements.

The client-side was implemented in standard HTML, CSS and JavaScript web technologies. JavaScript jQuery and Bootstrap libraries were used for improving the application user interface. The backend side was implemented in the PHP Laravel framework with MySQL database as database management system – DBMS.

The system has two groups of users: caretakers (patients) and caregivers (doctor, medical nurse or family member). To use the system, each user must be registered and signed in on mobile or web application. If you are logged in as a caretaker, you can only see data about yourself which includes the history of notifications and sensor measurements statistics. If you are logged in as a caregiver you can see the data about any patient, set different administration functionalities like measurement period per sensor, or send notifications. You can also start and stop measurements. If needed, it is easy to extend application so that caregiver X can only see some patients, and not all of them in which case an administrator will be needed to give or revoke access privileges.

IV. RESULTS AND DISCUSSION

The system was developed as a proof of concept, where the main goal was to create remote health monitoring system with the off the shelf hardware. To verify the applicability of the system two experiments were carried out. Both experiments were conducted from volunteers, students and professors in the College of Applied Technical Sciences Nis. Experiments with elderly were not conducted due to ethical reasons.

The first experiment involved 10 different people of different age, from 20 – 38. The people were instructed to perform series of activities in total duration of 5 minutes while wearing smart watch on their left hand, and mobile phone in their pocket. The activities included standing, sitting, laying, walking, and running, walking upstairs and walking downstairs. The results were monitored and recorded via web and Android application and later compared to verify that the system is working as expected.

The second experiment was conducted on 3 users and included monitoring the health and wellbeing of the patient for 24h. This study aimed to verify the applicability of the system for long term monitoring, energy consumption etc. It was also used to verify that the statistics and history about patient health is shown correctly. Let us briefly discuss and answer the research questions posed in the introduction of the paper.

Both experiments verified that the system correctly measures and monitors the health of the patients, and is working as described in the paper. There were some problems during the development of the system due to lack of standard or universal way in which the health data is saved or retrieved through API by different hardware manufacturers. The standards and software access to raw sensor data is still in the stage of rapid development. For example, during the implementation of the system we had to wait for Tizen operating system to update to version 3.0 so that we can access raw accelerometer data. The access was allowed only for native application, but not for the web wearable applications.

The system can measure hearth rate, activities, ambient light, atmospheric pressure, and accelerometer, gyroscope and magnetometer data. The list of activities is limited by API to stationary, walking, running and in the vehicle. It also enables bidirectional communication with rich user interface and interaction. Samsung gear S3 has advanced hardware capabilities in comparison with other wearable devices but is also more expensive. The main reason we choose it for the experiment was free access to two smart watches.

Other reason was to use a wearable that can best demonstrate the full capacity for modern patient monitoring in both different sensors that can be found on the device, and as well to communicate different information from caregiver to caretaker. For example, cheaper solutions do not have the ability to measure hart rate, or they cannot send visually rich notification or reminder. The API support for acquiring the data from device sensors is usually nonexistent or poorly supported, which makes communication between the wearable and phone difficult to implement. On the other hand, new (smart) wrist bands can provide some sensors offered by the smart watches, and at the same time wrist bands have longer autonomy, are less expensive, and can be less distracting for the user. This "distraction" can also be seen as a bad thing in case when a caretaker wants to urgently notify an elderly to take a medicine.

In comparison to systems that don't use a smartwatch or wearable device [4][5], we find that the system described here is more practical as it enables bi-directional communication. There is also a benefit that a large population of elderly is more accustomed to wearing the watch, and that a phone can be more easily misplaced. We also find that the system described in [8], where patient must wear different sensors on his body, as well as Bluetooth device that is strapped on his waist, is obtrusive and invasive as it can disrupt normal patient behavior.

The other monitoring systems described in related work section all describe systems intended to be deployed in some type of environment or health organization like a hospital. They require custom made hardware for sensing [6] or additional PIR motion sensors [12]. The cost of maintaining such a system for both hardware and software should be significant and should also be considered. They also disrupt normal patient behavior and require from a patient to adopt some changes in their daily routines.

In comparison, the system that we describe here uses only off the shelf hardware that will disrupt or change patient daily behavior as less as possible. We assume that patients, especially elderly, are already used to wearing watch and mobile phone. Therefore, the system we propose is intended for more general use, to assist and improve the wellbeing of elderly, and can be used by an organization like home for elderly or can be used independently. For example, a person can buy a smartwatch and monitor the health of his elderly father without the need for software maintenance.

The system described in this paper, as well as any system that monitors health of a person, has access to sensitive and private data. Therefore, the storage and access to persons data must be handled with great care due to moral and legal reasons. New law regulations like General Data Protection Regulation (GDPR) impose strict regulations on data protection and privacy for all individuals within the European Union. Questions like where health data should be stored, who can view a subject's medical record, to whom should this information be disclosed without the subject's consent, and who will be responsible for maintaining the data need to be addressed and appropriately handled when system is deployed.

V. CONCLUSIONS AND FUTURE RESEARCH

The main topic we address in this paper is remote health monitoring of the elderly people by using a smartwatch. The system described in this paper uses off the shelf smartwatch and mobile phone, without the need for any custom-made hardware. It enables bidirectional communication, remote measurement of hearth rate, basic activities, accelerometer, gyro eater and magnetometer data, ambient light and atmospheric pressure. It requires minimal change in patient's everyday behavior, and minimal maintenance cost, and thus marks an improvement or alternative to the similar solutions.

Although consumer-grade smartwatches have penetrated the health research space rapidly since 2014, smartwatch technical function, acceptability, and effectiveness in supporting health must be validated in larger field studies that enroll actual participants living with the conditions these systems target to monitor.

Detecting additional features by using machine learning technics, as well as assessing patient mental and social state, will be the subject of future research.

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