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A smartphone-based wearable sensors for monitoring real-time physiological data☆

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A B S T R A C T

Recently, Wireless Body Sensor Networks (WBSNs) have been popularly employed to measure people's physiological parameters, particularly for disease monitoring, prevention, and treatment. In this study, we propose a smartphone-based WBSN, named Mobile Physiological Sensor System (MoPSS), which collects users' physiological data with body sensors embedded in a smart shirt. A patient's vital signs are continuously gathered and sent to a smart phone in a real-time manner. The data are then delivered to a remote healthcare cloud via WiFi. After performing necessary classification and analysis, the health information of individual patients is also stored in the cloud, from which authorized medical staffs can retrieve required data to monitor patients' health conditions so that when necessary, caregivers are able to reach the patients as soon as possible and provide required assistance. Our simulations demonstrate that the presented healthcare system provides a better solution for health management.

1. Introduction

Over the past two decades, the ageing/greying population (65 +) reportedly constitutes almost 20% of the population worldwide [1]. Consequently, the number of greying-society patients requiring continuous monitoring have been hugely increased [2]. Chronic conditions, such as hypertension, high cholesterol, arthritis, diabetes, heart disease, cancer, dementia, etc., both in developed and developing countries, are some of the major concerns when taking care of elderly people [3,4]. To effectively detect and diagnose these diseases much earlier, a number of healthcare assistance systems, which can remotely monitor patients' health statuses so that when necessary, caregivers are able to reach and assist them as soon as possible, are required.

In recent years, many countries have suffered from lacking of skillful healthcare staffs [3,4]. On the other hand, high-tech products have been popularly developed in the world [5,6]. They actually make our everyday lives more conveniently and efficiently. Further, biomedical sensors and wearable devices provide an innovative method to record and retrieve health-related information from human body in real-time, enforcing ubiquitous sharing of such information by medical profession-

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als and healthcare staffs so as to improve the quality of their medical treatments and delivered healthcare. Our idea is that if we can integrate high-tech products, wearable sensors and a healthcare monitor system as a Wireless Body Sensor Network (WBSN) with which to monitor a patient's vital signs, the number of healthcare labors required can be then dramatically reduced. Particularly, the monitor can continue 24 hours, rather than instantly or lasting only a short period of time.

Also, nowadays, people carry smart phones wherever they go, meaning smart phones are close to body sensors, thus able to efficiently collect user's physiological information. A typical smartphone-based wearable monitoring system generally comprises body sensors, a wireless body area network (WBAN), and a healthcare cloud. Body sensors gather information from a person being monitored. The WBAN is often a low power network, allowing communications between body sensors and the collecting mechanism, like smartphones. This will realize continuous remote monitoring of user's health without any restriction on their everyday activities [7].

Moreover, smartphone-based healthcare systems as one type of remote healthcare systems can benefit users and healthcare professionals since the real-time information collected in and retrieved from remote healthcare cloud [8] often results in more accurate diagnosis on the person. Nevertheless, the significant amount of data received from the sensors will stress the monitor system, especially on data storage, classification, and/or related analysis [9]. Furthermore, a remote healthcare monitor system has other challenges, like data delivery quality, privacy preservation, and monitoring performance [10,11].

In this study, we extend our previous work in [12,13] by increasing its formal analysis on performance and further enhancing the wearable functions of the physiological sensor platform, hereafter referred to as Mobile Physiological Sensor System (MoPSS), which is designed to collect a user's physiological data from a smart shirt worn by the user. This shirt is equipped with different sensors, such as ECG, temperature, blood pressure, blood glucose, heart rate, and oxygen saturation sensors, which are embedded within the suitable places of the shirt. The device allows us to collect real-time physiological data, which is then displayed on the user's smartphone, and then uploaded to a healthcare cloud. The use of the cloud system enables us to store, classify, and analyze the user's vital information in a secure and privacy-preserving manner. The detailed descriptions of the MoPSS are presented later. In the following, we will use physiological data, vital signs and vital indexes, interchangeably.

The contributions of this paper are as follows.

1) The proposed system provides real-time feedback, i.e., issuing alert messages, when one or some of the vital signs, including temperature, ECG, HR, BP, BG, and SpO_2, of a monitored patient are abnormal. This can shorten the time period from the occurrence of the abnormal to the time when caregivers reach the patient so that they can assist the patient as soon as possible.
2) The physiological data collected in the MoPSS can be the big data, from which indicators of possible diseases may be discovered. This is one of the steps of preventive medicine.
3) We propose an innovative approach to synchronize the data collection from sensors, which are produced by different manufacturing companies, with different versions of Bluetooth protocols.
4) The personal health information gathered in the healthcare cloud enables medical professions and caregivers to access it for monitoring anytime and anywhere without restricting themselves in a specific geographical area.

The remaining of this paper is organized as follows. Section 2 presents related literature. The framework of the proposed system is introduced in Section 3. The functions of the MoPSS are simulated and its performance is analyzed and discussed in Section 4. Section 5 concludes the study and outlines our future research.

2. Related literature

Wearable sensors have widespread applications in different areas, such as medical [14,15], security (e.g., door/window sensor and motion detector), and education [16], since they provide accurate, reliable and real-time information on individual's behaviors and activities, thereby assisting users to detect possible problems. In the medical field, physiological sensors which are integrated with a WBSN to measure a patient's physiological indexes can be applied to disease monitoring, diagnosis and treatment, and health management. However, these wearable wireless sensors are envisioned to operate on human bodies. Therefore, the hardware and software constraints and the safety requirements, such as avoidance of physical injury, are medical and engineering challenges [14].

2.1. Wearable sensors

In the middle of 2000, the wearable products and technology have been successfully integrated as an advanced medical device. For instance, in 2013, Kańtoch [15] developed a health monitoring system to monitor and analyze human physiological signs. The system combines Bluetooth with an ECG sensor, a temperature sensor and a movement detector which are placed on the human body or integrated with clothes to acquire physiological data. The data are then forwarded to a remote medical server. The experimental results found that for a group of people after working or running, the system had a maximum of 5% absolute error compared to that of certified medical devices. In April 2014, the Industrial Technology Research Institute (ITRI) in Taiwan developed a mobile healthcare device, using smart wristbands and ambulatory ECG's patch to continuously monitor patient's heart rates and breathing conditions over a long duration. The ECG is attached to the user's chest to measure ECG, temperature and other physiological signals during his/her daily activities, such as walk, going

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