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Ubiquitous Healthcare System: Architecture, Prototype Design and Experimental Evaluations

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Abstract

Seamless and timely monitoring of patients remains an open challenge in current healthcare systems. The need especially arises for patients with chronic diseases and those susceptible to sudden change in their health, such as cardiac patients and elderly people. Hence, there is a need for designing an automated health monitoring system that could seamlessly and efficiently collect patient information. This can largely improve the decisions made by medical professionals, especially in emergency and time-critical cases. This work proposes the design of a ubiquitous healthcare systems, termed as Remote Health Monitoring System (RHMS) that offers flexible and cost-effective solution. RHMS is designed to be wearable, light-weight and comprise various small non-invasive medical sensors. Results show that RHMS has the potential to provide physicians continuous monitor of patients through a centralized observation system without patients being physically present at any medical facility.

Keywords: Arduino, Medical Sensors, Remote Health Monitoring, ZigBee.

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1. Introduction

Providing quality healthcare services for the expanding human population is turning into a genuine problem because of the limited medical centres and resources [1-3]. Misdiagnosis or late diagnosis of patient's condition can cause complications on serious chronic diseases, such as in Myocardial Infarction (MI) condition commonly known as heart attack. Hence, early and correct diagnosis of such diseases is important to potentially save lives of individuals, significantly improve their quality of life and reduce financial burden on individuals and governments. As a result, there is a strong need to timely and continuously monitor the patient's health condition by observing several health related parameters, including body temperature, pulse rate, blood pressure, heart electrical signal electrocardiogram (ECG) and body positioning [4, 5].

Ubiquitous healthcare systems is a promising approach that has the capability to collect health related information seamlessly by sensors attached to patient's body [6, 7]. Such systems can assist in monitoring the patient's condition in real-time, anytime and anywhere [8, 9]. As a result, the initial signs and symptoms can be detected earlier that can lead towards predicting patients' future conditions, both physically and physiologically. This in-turn can help in reducing health care costs while simultaneously improving patient care outcomes. This can be obtained through the usage of one or more wearable sensors attached to the patient's body [10].

Indeed, critical decisions made by the medical staff can largely depend on the gathered information originating from such wearable sensors. Several ubiquitous healthcare systems have been proposed previously but with week focus on the design aspects of a remote healthcare monitoring solution that can be adopted both at a home setup and within a medical facility [11, 12]. The motivation for building a system with remote health monitoring feature is to allow mobility and flexibility for both the patients and medical staffs along with improving the quality of healthcare services [13]. In this paper, we propose the design of a Remote Health Monitoring System (RHMS) that would continuously monitor the patient's condition and accordingly update the concerned medical staff. In the proposed system, a patient can be residing at his/her home or within a hospital, while the medical staff would receive the continuous updates at the medical centres. The proposed system would also target hospitals for replacing large and expensive bedside machineries that are used to monitor patient conditions.

Such systems are Internet of Things (IoT) based systems that are expected to reduce the number of hospital visits hence leading to the reduction of both the time spent for visiting medical centres along with the associated costs. Furthermore, the proposed RHMS aims to provide services to those people who cannot afford frequent check-up expenses or elderly people for whom travelling is a difficultly. The RHMS can also facilitate easy monitoring of admitted patients in hospitals and reduce the burden on heavy equipment by avoiding unnecessary diagnosis tests. The application of RHMS in hospitals setup can reduce the frequency of nurses' visits at the bed side along with providing prior results before dealing with emergency cases. As a result, the proposed system can also improve the performance levels of medical staff within hospitals.

The proposed design for the RHMS can also aid medical staff in decision making process, by having access to a large corpus of observational data stored in a centralized cloud based setup [14]. Gathering an accurate, abundant and timely information related to the patients can provide medical staff with the ability to take better decisions by analysing the previously gathered records. In addition, physician and patient's family members will be able to access the patient's medical information at anytime and anywhere. Physician or family members can receive alert messages if some of the vital sign parameters exceeds the clinical thresholds sets. This will enhance the level of medical support and feedback that patients can receive at their homes while doing their daily routines.

Rest of the paper is organized as follows. Section 2 discusses the related work. Section 3 describes design of the proposed RHMS. Section 4 discusses the two employed case study scenarios along with presenting and discussing the obtained results. Finally, Section 5 concludes this work and provides future directions.

2. Related Work

The widespread application of ubiquitous health monitoring devices along with their integration with communication technologies for remote access to patient conditions is envisioned to be a core application within the spectrum of the Internet of Things (IoT) [4, 15-17]. Remotely checking of health parameters using e-Health and m-Health systems has drawn a critical sight from the investigation gathered in the last decade or so [18-20]. Different and yearly extending of creative work attempts have been posted in the composed works along with several proposals from the perspective of design and implementation [21, 22]. In this section, we have confined this push to consolidate only a part of the outstandingly and the most recent related works.

Continuous portable medicinal services framework for checking the elderly patients from indoor or open air areas has been discussed and presented in [23]. The system used ANT protocol, which is a multicast wireless sensor network technology that works in the range of 2.4GHz ISM band. It has a low range and low-data-rate, hence, less power consumption. A bio-flag sensor and a cell phone are the principle parts of the framework proposed in [24]. The information gathered by the bio-flag sensor are transmitted to a server by means of GPRS/UMTS. The sensor can remotely screen versatility, area, and imperative indications of elderly patient.

A smart intelligent shirt has been outlined in [25], where the shirt can gauge electrocardiogram (ECG) and quickening signals for consistent and constant checking of a patient. The shirt primarily comprises of sensors and conductive textures to get the body flag. The deliberate body signs are transmitted to a base station and server PC by means of IEEE 802.15.4 communication standard. The wearable gadgets consume low power and they are sufficiently little to fit into a shirt. To decrease the noisy particles connected with the ECG flag a versatile sifting technique has likewise been proposed in this work.

Windows Mobile based framework for observing body parameters has been exhibited in [26]. The proposed framework comprises of a body sensor organize that is utilized to gauge and gather physiological information. Bluetooth has been utilized to transmit information from the sensor system to a cell phone. The unwavering quality and heart scheduling of the proposed framework has been checked by the authors. The trial comes about demonstrate that the proposed framework can screen the physiological information of patients under versatility condition.

Existing ubiquitous healthcare wearable systems were proposed to monitor and diagnose the cardiac status and the overall health condition by utilizing smartphones, low-power communication protocols and non-invasive sensors. Many of such systems were proposed during the last decade and many are still emerging. In this paper we propose a new system design which attempts to meet the requirements stated above.

3. Proposed System Design for RHMS

The proposed RHMS is divided into two parts, which are Hardware Interfacing and the associated Software modules. The Hardware interfacing part consists of two modules, namely Arduino and the wearable Sensors, whereas the Software part consists of the following three modules: Database, Web Server and Web Application. The Database and webserver are considered as the backend system, which is handled by RHMS developers, whereas Web Application is designed for visual purpose to monitor and manage the results in the most appropriate manner. The diagram shown in Figure 1 explains the basic components of both the hardware and software parts. Details of the overall system are discussed in the following subsection.

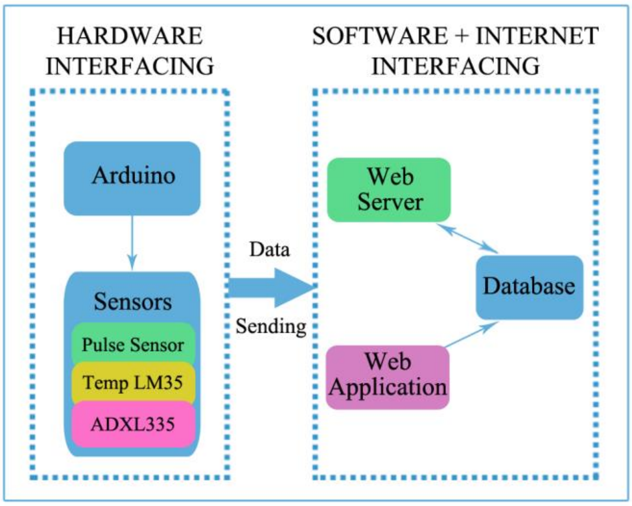

Figure 1. Basic components of Hardware and Software parts in the RHMS system.

3.1. Hardware Design

To keep pace with requirements of current times, the proposed system has been designed to be wearable, lightweight, non-invasive, reliable and with wireless transceiver. Moreover, since the wearable RHMS systems are preferred to be with low-cost and low-power consumption, the transmission medium needs to be selected properly. In most research work, Bluetooth and Wi-Fi transceivers were used as the communication technology due to their high payload size. However, Bluetooth and Wi-Fi generally have high power consumptions making them as unsuitable options for resource constrained devices as being as essential need for IoT based solutions [15]. On the other hand, ZigBee provides small amounts of data rate over a short distance and while consuming very little power making it a more suitable option [27].

To confirm the idea of wear-ability of the proposed RHMS device, Lilypad Arduino was used as the central control unit. Lilypad board is a light-weight Arduino platform that is designed to be easily integrated into e-textiles and wearable projects [8]. It consists of an ATmega328 microcontroller and runs on 2 ~ 5V supply. The medical sensors were connected to Lilypad that extracts and processes the data from the sensors. Multiple sensors including pulse sensor, accelerometer, ECG sensor and body temperature sensor, is compatible with Lilypad. For the case of this work, only two sensors are considered: i.e. Pulse Sensor Amped to measure the heart beat and LM35 temperature sensor to measure body temperature.

The Pulse Sensor Amped is a plug-and-play heart-rate sensor for Arduino that allows to measure the heart rate in real time or record the heart rate. It has amplification and noise cancellation circuitry in its hardware. Furthermore, it works with either a 3V or 5V and draws a maximum current of 4mA at 5V. The sensor is simply clipped to earlobe or finger-tip. The LM35 is a high precision integrated-circuit temperature sensor with an output voltage linearly proportional to the Centigrade temperature. It draws only 60μA from its supply and process a low self-heating capability which causes less than 0.1°C temperature rise in still air, making it very suitable for our application.

For further implementation, a third sensor namely the ADXL335 triple axis accelerometer is used for body positioning. However, this work will show the results of two sensors only, while the accelerometer sensor results will be included in future papers. Table 1 provides a summarized outlook for the sensors used in the proposed RHMS along with their technical specifications.

Table 1. Summary of Sensors Specifications.

Sensor	Purpose	Operation Parameters
Pulse Sensor Amped	Measures heart rate of patient	3V or 5V Max. 4mA
Temperature Sensor (LM35)	Measures temperature of patient	4V ~ 30V Max. 60μA
Triple axis accelerometer (ADXL335)	Estimates body positioning	1.8V ~ 3.6V Typical 350 μA

In general, the heartbeat rate and body temperature does not require high data rates. Body temperature is usually monitored every few minutes because physically the temperature of the body changes slowly, while the heart beat changes every few seconds.

The ZigBee wireless communication module, known as Xbee is used [11]. In the designed system, the Xbee module works as a transmitter for another Xbee module, i.e. the receiver. The receiver end is further connected with a microcontroller or Arduino board, which will have a built-in Wi-Fi to communicate with a router. If the patient is at home, then the router will be sending data to the hospital side database through the internet. In case a patient is in the same hospital then communication will be through local network inside the hospital. The final look of the proposed system is as shown in Figure 2, where it is designed to be like a wristwatch with sensors integrated.

3.2. RHMS Architecture

A software interface is developed to complement the hardware prototype. The software part is mainly composed of a Web Application, Webserver and a Database. The Database stores patient's information such as medical record

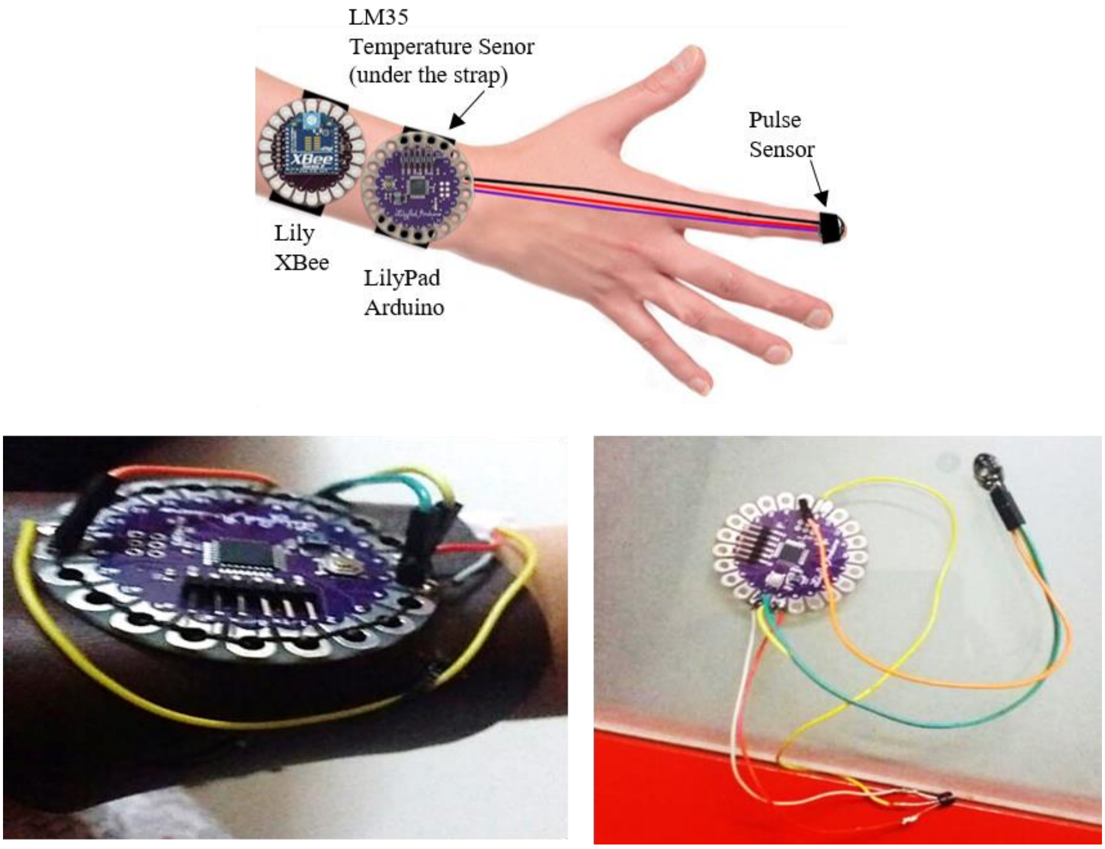

Figure 2. Prototype for the designed RHMS
(above: illustration of the system, below: actual implementation).

number (MRN), name, gender, age, home address, contact of concerned family members or other legally qualified person and a real-time monitoring progress report. The Web Application or Smart Phone Application can be used to monitor the health of patients. Such applications will allow real-time monitoring of the vital signs that can be viewed by physicians or other concerned medical staffs. The hardware is integrated with the software interfacing as follows:

- **Creating a Database:** MySQL database server was created on a Localhost using XAMPP software. The database was designed to hold the real-time data of patients in tables. Each table holds patient’s personal information, heart beat rate, body temperature, time and date span, etc.
- **Sending Data to Excel:** To maintain and send the real-time data acquired from Arduino to the database, PLX-DAQ software was used. This software transmits the information from Arduino to MySQL database that are further saved in excel sheets.
- **Creating a Web Application:** A Web Application was created using PHP and HTML coding to view and manage the stored information in the database. The web application has a secured login page that allows admin users to access and enter the patient records. JavaScript was used to link the web application with the database.
- **Graphic Visualization:** For the front-end, a graphical interface was designed to display the data in real time. In addition, the interface allows the retrieval and display of the old stored data if needed.

The system can send an alert to the physician if there are any abnormalities in the vital signs. As a result, quick emergency services can be received by the physician along with crisis administrations. As a result, it is not required to have a physical accessibility to the physician at the time of emergency. This gives a more proactive patient services that not only it enhances personal satisfaction, but would also reduce medicinal services costs. Moreover, this would provide greater access to patient’s health related data and an ability to continuously monitor patient condition, regardless of patient’s location. The system can also facilitate to receive alerts for anomalies, serious events, even skipped doses, support an increased level of accuracy for clinical monitoring readings and increase the level of trust and reliance that physicians place in data.

Figure 3 presents a three layered overall architecture of the proposed RHMS system, encompassing the wearable components, the communication technologies and the monitoring applications. The system is designed to ease the usage and accessibility to the patients as well as to the concerned medical staff.

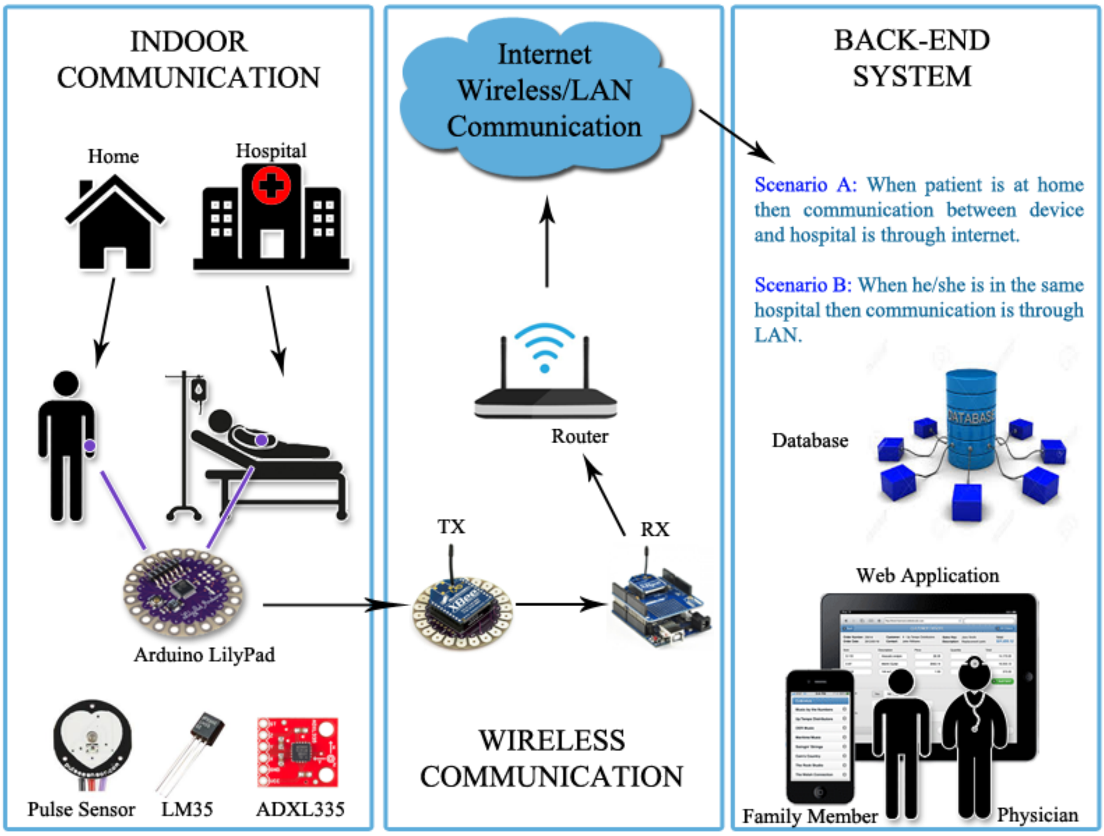

Figure 3. System's overall architecture of the RHMS along with the used hardware and software components and communication modules.

(a) (b)

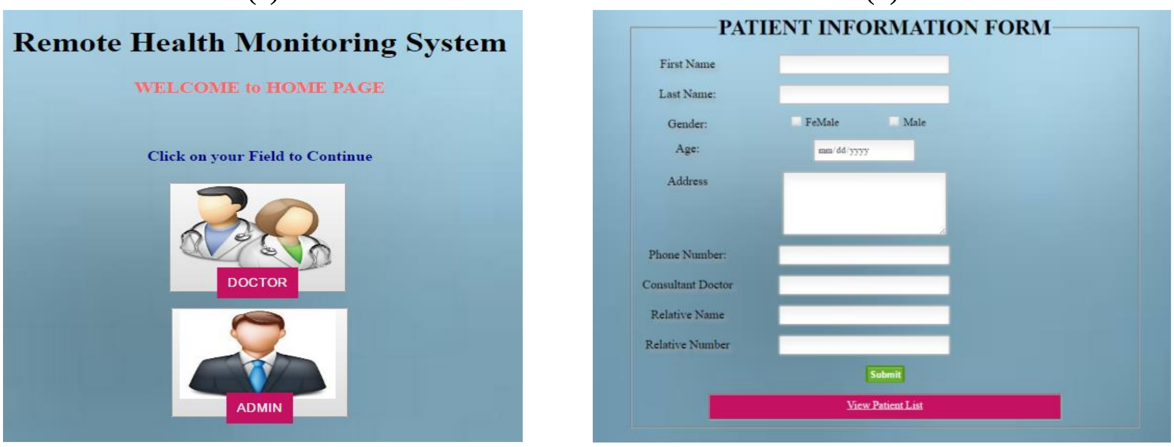

Figure 4. Front-end or web application of RHMS designed: (a) Main homepage (b) New patient form entered by admin.

In the first layer of the proposed RHMS, the vital sign signals are sensed from inpatients and outpatients using sensors attached to Arduino LilyPad, which acts as the processing unit. Then, Arduino LilyPad sends the sensed data to the wireless communication module which in turn sends the data to a back-end system through Internet or LAN connection, depending on location of the patient. At the back-end system or the final layer, the data is stored in a secured database that allows only the authorized people to access and visualize the patient's data using Web application or Smart Phone Application. The developed software includes the main Web Application interface, as shown in Figure 4 (a). Through this interface, we can select either a Doctor or Admin login option. By using the Admin login, we can enter new patient record or check existing patient record. Whereas, selecting “Enter New Patient Record” shows a form that has to be filled with patient details as shown in Figure 4 (b).

4. Results and Discussion

The overall system has been evaluated in terms of functionality and performance. The prototype performance has been validated by checking the sensors’ readings and the communication protocol. The prototype was able to send the sensed data from the transmitter Xbee module to receiver Xbee that was able to the data to the Database Web Server through Internet connection. The prototype was tested indoor using WiFi router and outdoor using LAN connection successfully. This test showed that the system can be used ubiquitously anywhere and everywhere.

Experimental evaluations for the clinical data have been conducted using the designed RHMS with real human volunteers. The following results have been achieved for the two case scenarios. In the first case, we have taken a young aged subject (21 yrs., Male) whose medical record is healthy. The second case is for an old aged subject (57 yrs., Male) whose suffers from a chronic heart disease. The temperature readings have been measured every 1 minute, while the pulse rate has been measured every few seconds.

The results show that the first subject is having normal temperature readings with an average of 36.58^{o}C as shown in Figure 5 and a heart rate ranging between 76 and 95 BPM with low fluctuation within a period of approximately of 7 minutes as shown in Figure 6. These results are consistent with the subject’s health condition. On the other hand, the second subject showed sudden changes in the heart rate compared to a healthy person whereas at the 3rd minute it drops from 86 BPM to 60 BPM within half a minute.

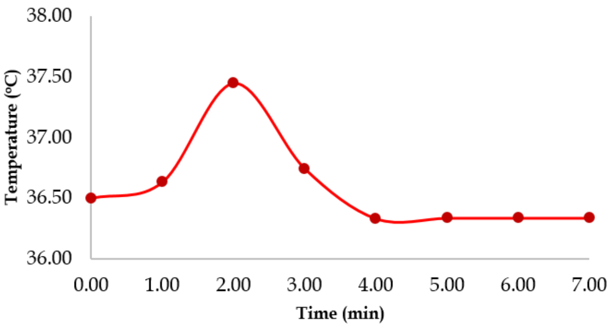

Figure 5. Temperature Graph for a healthy young aged subject.

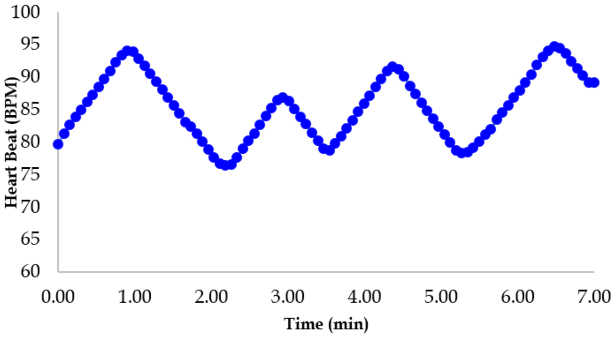

Figure 6. Pulse Graph for a healthy young aged subject.

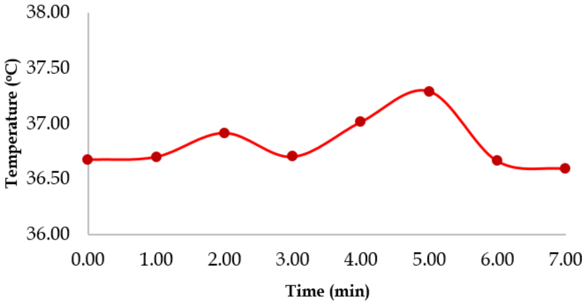

Figure 7. Temperature Graph for a non-healthy old aged subject.

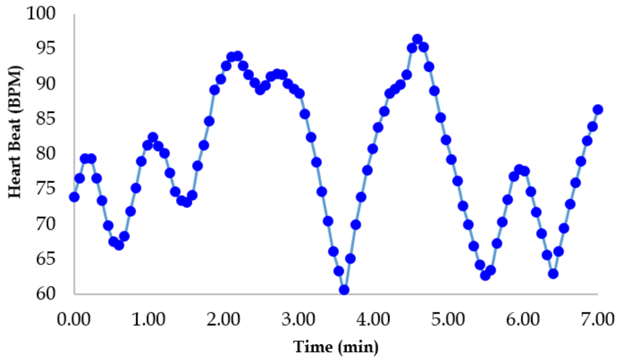

Figure 8. Pulse Graph for a non-healthy old aged subject.

Results of the second subject are shown in Figure 7 and Figure 8. These results show promising outcomes using the real-time monitoring system. This system can facilitate the immediate action by physicians to provide proper medication and treatment to the patient immediately. In the future, more subjects will be involved in clinical study to get more results.

5. Conclusion and Future Directions

Expanding rate of constant health related emergency in large population is turning into a genuine problem because of absence of adequate medical centres and to a great degree of high cost. This situation is even worse for the old age people as some disease require a constant check-up for better assessment of those disease the issues that take are far distance from medical facilities as delay in diagnosis and treatment may lead to death. Timely diagnosis and treatment can solve these issues to a great extent. The advancements in wireless communications and remotely data gathering of disease can help in various ways. The wearable sensor and transferring of data to database in case of any health issue can help the medical personal and patient to communicate before any health bad condition. This technology opens up the opportunity of real-time healthcare monitoring systems.

In this study, a real-time health monitoring system (RHMS) that measures the heart rate and body temperature of patients has been proposed. The proposed system was designed to be wearable as a wristwatch by using a light-weight Lilypad Arduino that acts as a central processing unit, a low-power ZigBee wireless transmission technology and small non-invasive medical sensors. The proposed system proved its ability to transmit patient data to a Database and then display them on a Web Application. The Web Application allows authorized Admin users to monitor and visualize the medical records. Future work of our proposed system is to complete the overall architecture, as well as including new low-power sensors such as the body-positioning sensor and ECG sensor.

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