REAL TIME WIRELESS HEALTH MONITORING APPLICATION USING MOBILE DEVICES

Amna Abdullah, Asma Ismael, Aisha Rashid, Ali Abou-ElNour, and Mohammed Tarique

Department of Electrical Engineering, Ajman University of Science and Technology, P.O. Box 2202, Fujairah, United Arab Emirates

ABSTRACT

In the last decade the healthcare monitoring systems have drawn considerable attentions of the researchers. The prime goal was to develop a reliable patient monitoring system so that the healthcare professionals can monitor their patients, who are either hospitalized or executing their normal daily life activities. In this work we present a mobile device based wireless healthcare monitoring system that can provide real time online information about physiological conditions of a patient. Our proposed system is designed to measure and monitor important physiological data of a patient in order to accurately describe the status of her/his health and fitness. In addition the proposed system is able to send alarming message about the patient's critical health data by text messages or by email reports. By using the information contained in the text or e-mail message the healthcare professional can provide necessary medical advising. The system mainly consists of sensors, the data acquisition unit, microcontroller (i.e., Arduino), and software (i.e., LabVIEW). The patient's temperature, heart beat rate, muscles, blood pressure, blood glucose level, and ECG data are monitored, displayed, and stored by our system. To ensure reliability and accuracy the proposed system has been field tested. The test results show that our system is able to measure the patient's physiological data with a very high accuracy.

KEYWORDS

ZigBee, remote healthcare, mobile device, patient monitoring, LabView

1. INTRODUCTION

Health is one of the global challenges for humanity [1]. According to the constitutions of World Health Organization (WHO) the highest attainable standard of health is a fundamental right for an individual [2]. Healthy individuals lead to secure their lifetime income and hence to increase in gross domestic product and in tax revenues. Healthy individuals also reduce pressure on the already overwhelmed hospitals, clinics, and medical professionals and reduce workload on the public safety networks, charities, and governmental (or non-governmental) organizations. To keep individuals healthy an effective and readily accessible modern healthcare system is a prerequisite.

A modernized healthcare system should provide better healthcare services to people at any time and from anywhere in an economic and patient friendly manner. Currently, the healthcare system is undergoing a cultural shift from a traditional approach to a modernized patient centered approach. In the traditional approach the healthcare professionals play the major role. They need to visit the patients for necessary diagnosis and advising. There are two basic problems associated with this approach. Firstly, the healthcare professionals must be on site of the patient all the time

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and secondly, the patient remains admitted in a hospital, wired to bedside biomedical instruments, for a period of time. In order to solve these two problems the patient oriented approach has been conceived. In this approach the patients are equipped with knowledge and information to play a more active role in disease diagnosis, and prevention. The key element of this second approach is a reliable and readily available patient monitoring system (PMS).

The need for a real time recording and notification of vital signs of a patient is of prime importance for an effective PMS. By encapsulating the advantages of modern bioinstrumentation, computers, and telecommunication technologies a modern PMS should acquire, record, display, and transmit the physiological data from the patient body to a remote location at any time. For more efficient, timely, and emergency medical care the PMS must also be incorporated with an alarm system. In order to alert the patient as well as the health care service providers the PMS should not only monitor and analyze the critical patient's data but it should also send alarming messages in case the monitored data go outside their normal ranges. Hence, an active database system must be associated with the PMS. Most of the proposed PMSs are centralized in a sense that all patients' data are stored in a single server. By using necessary firmware and software the server can be connected to an open communication network via TCP/IP protocol. Thus a patient can be monitored from a remote location. Existing and widespread mobile phone networks can assist in this regard.

Recently, mobile networks are considered critical for solving future global health challenges [3]. With the global market penetration of the mobile phones the mobile healthcare system (i.e., m-Health) is a matured idea now. By using the mobile phone healthcare system can be made available for people, who are living in remote areas without much access to other types of communications. Even a simple mobile phone can become a powerful healthcare tool now. Text messages and phone calls can quickly deliver real-time and critical information of a patient to a remote location. Thus the patients, living in remote areas, can reduce unnecessary back-and-forth travel to the far located healthcare centers. However, mobile devices have become "smart" now to do more rather than simply transmit medical information and advice.

Smartphone, supported with high speed data services, has revolutionized healthcare by playing the role of a powerful medical device for monitoring the patients' health. Heart disease and diabetics monitoring and controlling systems are very much common now. An estimated 95,000 healthcare applications are available today and over 200 million people have downloaded these applications to their smartphones [4]. It is estimated that 500 million people will be using healthcare applications by the year of 2015 [5]. It is also estimated that smartphones and tablets will be the most popular technological developments for doctors since the invention of the stethoscope. In the United States smartphones are being used by the physicians not only to access medical reference material, training contents, and professional journals but also to use them for patient monitoring, imaging, and bedside care. Smartphones enable patients to take a more active role for the betterment of their own health such as managing appointments, updating prescriptions, and accessing their medical records. Thus smartphones have maximized healthcare professionals' time and enhanced the efficiency of the existing healthcare systems.

In this paper we present a smartphone based wireless healthcare monitoring system (WHMS), which can provide real time online information about medical status of a patient. In addition alarming and reminding messages about the patient health status can also be sent to patient mentors for necessary medical diagnosis and advising. The proposed system consists of sensors, a data acquisition unit, smartphone, and the LabVIEW program. The system is able to display, record, and send patient's physiological data. Moreover, the proposed WHMS also supports

Internet connectivity so that the healthcare professionals can monitor and access patients' data from anywhere of the world at any time. The patient is equipped with biomedical sensors, which transform the changes in the monitored physiological quantities into electronic data that are measured and recorded. The LabVIEW program assists monitoring and displaying the data. The patient's temperature, heart beat rate, muscles, blood pressure, blood glucose level, and ECG data can be monitored by our present system. Our careful design of the hardware and software components of the system is able to fulfil any further requirement of the users.

2. Related Works

Wireless health monitoring system (WHMS) has drawn considerable attentions from the research community as well as industry during the last decade. Numerous and yearly increasing research and development efforts have been posted in the literatures. We have limited this effort to include only some of the very recent related works.

Real time mobile healthcare system for monitoring the elderly patients from indoor or outdoor locations has been presented in [6]. A bio-signal sensor and a smartphone are the main components of the system. The data collected by the bio-signal sensor are transmitted to an intelligent server via GPRS/UMTS network. The system is able to monitor the mobility, location, and vital signs of the elderly patient from a remote location.

A smart shirt has been designed in [7]. The shirt can measure electrocardiogram (ECG) and acceleration signals for continuous and real time health monitoring of a patient. The shirt mainly consists of sensors and conductive fabrics to get the body signal. The measured body signals are transmitted to a base station and server PC via IEEE 802.15.4 network. The wearable devices consume low power and they are small enough to fit into a shirt. To reduce the noise associated with the ECG signal an adaptive filtering method has also been proposed in this work.

Windows Mobile based system for monitoring body parameters has been presented in [8]. The proposed system consists of a body sensor network that is used to measure and collect physiological data. Bluetooth has been used to transmit data from the sensor network to a mobile device. The reliability and robustness of the proposed system has been verified by the authors. The experimental results show that the proposed system is able to monitor the physiological data of patients under mobility condition.

A complete wireless body area network (WBAN) system has been designed in [9]. The proposed system uses medical bands to obtain physiological data from sensor nodes. The author has chosen medical bands in order to reduce the interference between the sensor device and other existing network devices. To increase the operating range multi-hopping technique has been used and a medical gateway wireless board has been used in this regard. This gateway has been used to connect the sensor nodes to a local area network or the Internet. By using Internet the healthcare professionals can access patients' physiological data from anywhere at any time.

Many health monitoring systems use wearable sensors that produce continuous data and generate many false alerts. Hence, these systems become unsuitable for use in clinical practice. To solve this problem some machine learning approaches have been proposed in [10]. In these approaches data generated by the wearable sensors are combined with clinical observations to provide early warning of serious physiological changes in the patients. The effectiveness of these approaches has been tested at Oxford University Hospital. The test results show that the proposed system can successfully combine data acquired from the wearable sensors. Combining these data with manual observations the clinical staff makes important decisions about the patients.

Cloud computing has been incorporated in a healthcare system in [11]. The authors have proposed a cloud based intelligent healthcare monitoring system (CIHMS) for providing medical feedback to a patient through cloud. The proposed system can obtain adequate data related to patient's disease and deliver the data to a remote location by using cloud computing devices.

Although mobile devices are always considered a promising tool to monitor and manage patients' own health status, these devices have some inherent limitations in computation or data intensive tasks. A new hybrid mobile cloud computational solution has been proposed in [12] to overcome these limitations. The authors have introduced a mobile cloud based electrocardiograph monitoring system. The experimental results show that the proposed system can significantly enhance the conventional mobile based medical monitoring system in terms of diagnostic accuracy, execution efficiency, and energy efficiency.

To monitor the health of a pregnant woman with preeclampsia a novel health monitoring system has been proposed in [13]. The system has been designed for the community based health care providers so that they can collect symptoms and perform clinical measurements at the patient's home. The clinical data are used to predict the risk level of a patient. Based on the risk level the system provides recommendations for treatment, referral, and reassessment. The proposed system also uses an Oximeter connected to a smartphone to measure oxygen saturation level of the patient in order to predict her risk level.

Remote healthcare system for monitoring electrocardiographic and temperature data has been presented in [14]. The system consists of three modules namely (i) a hardware module, (ii) Bluetooth module, and (iii) display module. The hardware module is used for data acquisition. The Bluetooth module is used for data transmission. Finally, the data are displayed by using the display module. The acquired clinical data are sent to a database server by using GPRS or WiFi. The performances of the system have been tested on different patients and it has been found that the proposed system is very helpful for the physicians.

Mobile device based healthcare system for monitoring the patients with Alzheimer's disease has been developed and presented in [15]. The system is able to provide caregivers and medical professional with the ability to be in contact with the patients all the time. This system has been field tested by the Alzheimer's disease caregivers and the initial results show that the system is very effective for them.

A novel 6LoWPAN based ubiquitous healthcare system has been presented in [16]. The system integrates forwarding nodes and an edge router to provide real time monitoring of the ECG, temperature, and acceleration data of a patient. The user can send instructions to any node where the application running on it. The authors have used LabVIEW program to provide the connectivity. The whole system was tested by using an ECG simulator. The test results show that the received waveforms were found identical to those shown by a high resolution ECG signals.

An ambulatory system for monitoring the physical rehabilitation patients has been reported in [17]. The system consists of (i) a multi-sensor based monitoring device, (ii) a mobile phone with client application, (iii) a service-oriented-architecture based server solution, and (iv) an application. The system has been tested in a controlled environments consisting of some healthy volunteers and some congestive heart failure patients. The test results show that the proposed system is able to detect and monitor congestive heart failure and it can send feedback to the nurses for patient follow-up.

Real time ubiquitous healthcare system for monitoring ECG signals by using mobile device has been presented in [18]. By using this system the user can monitor his ECG signal. The authors have presented an algorithm for abnormal heartbeat detection and abnormal heartbeat check map (AHCM). The performance of the proposed system has been evaluated against the MIT-BIH normal arrhythmia database. It has been reported that the system is able to detect at an R-peak with a success rate of 97.8% and it is also able to detect abnormal heartbeat condition with a success rate of 78.9%.

A pervasive healthcare system enabling self-management for chronic patients has been introduced in [19]. The proposed system consists of (i) patient health monitoring system, (ii) status logging, and (iii) social sharing of the recorded information. The system has been implemented by (i) a mobile device, (ii) a wearable multi-sensing device, (iii) a service-oriented architecture for communication, and (iv) microblogging services. The system has been tested on 16 patients. The test results show that the proposed system is very easy to learn and convenient to use by the chronic patients.

Wireless electrocardiogram (ECG) monitoring system based on Bluetooth Low Energy (BLE) technology has been reported in [20]. The system consists of (i) a single-chip ECG signal acquisition module, (ii) a Bluetooth module, and (iii) a smartphone. The system is able to acquire ECG signals through two-lead electrocardiogram (ECG) sensor. The system is also able to transmit the ECG data via the Bluetooth wireless link to a smartphone for further processing and displaying the ECG signals. The results show that the proposed system can be operated for a long period of time due to low power BLE technology.

Breathing rate monitoring (BREMON) system has been proposed in [21]. The system allows paramedics to monitor the breathing activities of patients by using a smartphone. The system uses the smartphone based accelerometer to monitor the breathing activities of a patient. The acceleration data are then processed to calculate the number of breaths per minute (BPM). The data are then sent to the paramedics via a multi-hop network.

A system to monitor the blood pressure of a hypertensive patient using mobile technologies has been proposed in [22]. By using the system a doctor can carefully monitor the patient and can perform diagnosis. The system is implemented on the Java platform and it can reside in a small capacity device. The system is also able to communicate with a server via Internet. The server is used for storing and displaying patient data graphically.

In order to monitor the breathing disease called Obstructive Sleep Apnea Syndrome (OSAS), occurs due to sleep disorder, has been introduced in [23]. This disease not only interrupts normal sleep pattern but also causes hypoxemia and hypercapnia. In this work a smartphone based wireless e-health system has been introduced for monitoring a patient with OASAS. The authors show that the proposed system is very energy efficient due to the use of Bluetooth.

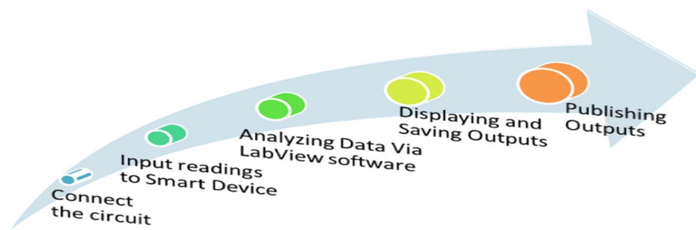


Figure 1. System operating steps

In our work we presents LabVIEW based patient monitoring system. The system operation is completed in five main steps as shown in Figure 1. We consider two techniques (see Figure 2) to implement the system. In the first technique we connect the sensors attached with the patient's body to a transmitter unit associated with a ZigBee or GSM network. The transmitter transmits the data wirelessly to a receiver that is also associated with a ZigBee or GSM network. The receiver is connected directly to the USB port of a local monitoring unit (which is a Laptop with LabVIEW software in it). The local monitoring unit displays the final data. This first technique is illustrated in Fig. 2(a).

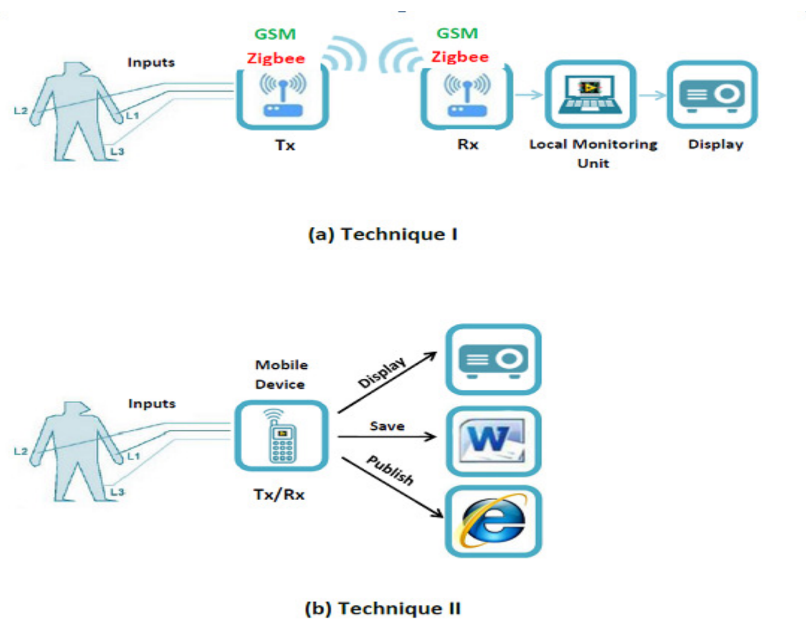


Figure 2. Investigated Techniques

In the second technique as shown in Figure 2(b) we connect the sensors attached with the patient's body to a mobile device. The mobile device acquires the data from the sensors and sends them to a processor, which is running the LabVIEW software in it. The processor receives the data and performs the necessary analysis. It can display the data in an organized Graphical User Interface (GUI). The processor also saves the data in a worksheet associated with the Microsoft Excel program. Finally, it can publish the data in the Internet so that the healthcare professionals can monitor them from a remote location at any time. In this proposed system we minimize the hardware by combining transmitter, receiver, and local monitoring unit in one device. The prime objectives of this system are as follows: (a) it saves the patients' time and effort by reducing their back and forth travel to health clinics, (b) it provides the patients with an opportunity to save their lives by sending them critical alarm message, and (c) it also assists the healthcare professionals and relatives to monitor the patients from a remote location. We implement this work by using hardware and software in such a way so that it can be easily accessed by different systems and devices. We made the system flexible enough to accommodate more options as per user demand in future.

3. SYSTEM IMPLEMENTATION ALTERNATIVES

In order to implement the system we consider some commercial, business, and engineering aspects namely cost, simplicity, efficiency, easy-to-use, low energy consumption, and environment friendly. Based on these aspects we consider four different alternative solutions namely (a) Microcontroller and Smart Phone, (b) USB audio interface for the iPad, (c) Yocto-Knob device, and (d) E-Health Sensor Platform V2.0 for Arduino and Raspberry PI.

In microcontroller and smartphone based solution we connect the EFM32 Tiny Gecko microcontroller with a smart phone using the audio jack interface of the phone. The EFM32 microcontroller communicates and harvests power from the phone. This solution is based on an Apple iPhone and the "HiJack" concept introduced by the researchers at the University of Michigan. This solution is applicable to any smartphone that can use this audio interface both for headphone output and microphone input. This supports two way communications between the EFM32 and the mobile phone.

In USB audio interface for the iPad solution we can connect an external USB audio interface to an iPad Camera Connection Kit. This allows for a standard audio equipment to be connected to the iPad as well as for dual channel input. Oscilloscope probes can also be connected to the iPad by using a BNC connector. The other devices that can also be connected include Griffin iMic, Numark STEREOliO, and Behringer UCA202. They all provide line level input and some of them would also have line/mic level switch. Feeding signals directly to the microphone jack is a bit complicated as the iDevice expects a particular load in order to "detect" external microphone. To use the mic we connect 1K resistor in parallel with the input. But, in both iDevices we need to install Oscilloscope for iOS. Its GUI includes many standard oscilloscope controls such as: triggering, time and voltage per division, and signal measurement cursors.

The Yocto-Knob device supports easy reading of 5 input buttons, contacts, switches or potentiometers (knobs) from USB. It is a kind of analog-to-digital converter (ADC). We can use it to read any analog resistive sensor including photodiodes. On the device, five tiny LEDs constantly show the value of the five inputs. Five micro switches connected in parallel to the inputs simplify a design. This device can be connected directly to an Ethernet network using a YoctoHub-Ethernet or to a Wi-Fi network using a YoctoHub-Wireless. Android application called Valarm Pro v1.1.0 provides support for the Yocto-Knob sensor. We can use these sensors to trigger alerts and/or record the conditions of a variety of stuff one might need to monitor without any programming. The Valarm Pro application integrates Yoctopuce sensors to monitor, record, and broadcast alerts based on environmental and weather parameters such as CO2, VOCs (Volatile Organic Compounds), ambient temperature, relative humidity, barometric pressure, ambient light, electrical resistance, water Levels, and flood alerts. The Valarm Pro currently integrates with the Yocto-Meteo, Yocto-Temperature, Yocto-Light, Yocto-Knob, Yocto-VOC, and Yocto-CO2.

The e-Health Sensor Shield V2.0, as shown in Figure 3, allows Arduino and Raspberry Pi users to perform biometric and medical applications where physiological data monitoring is needed. Ten different sensors can be connected to this e-Health Sensor Shield including pulse, oxygen in blood (SPO2), airflow (breathing), body temperature, electrocardiogram (ECG), glucometer, galvanic skin response (GSR-sweating), blood pressure (sphygmomanometer), patient position (accelerometer), and muscle/electromyography sensor (EMG). The biometric information collected by the sensors can be used to monitor the real time health status of a patient in order to be subsequently analyzed for medical diagnosis. The information can be wirelessly sent by using any of the six connectivity options available including Wi-Fi, 3G, GPRS, Bluetooth, 802.15.4, and ZigBee depending on the application. If a real time image diagnosis is needed, a camera can also be attached to the 3G module in order to send photos and videos of a patient to a medical diagnosis center. Data can be sent to the Cloud in order to perform permanent storage and visualization in real time by sending the data directly to a laptop or smartphone. IPhone and Android applications have been designed in order to easily monitor the patient's information.

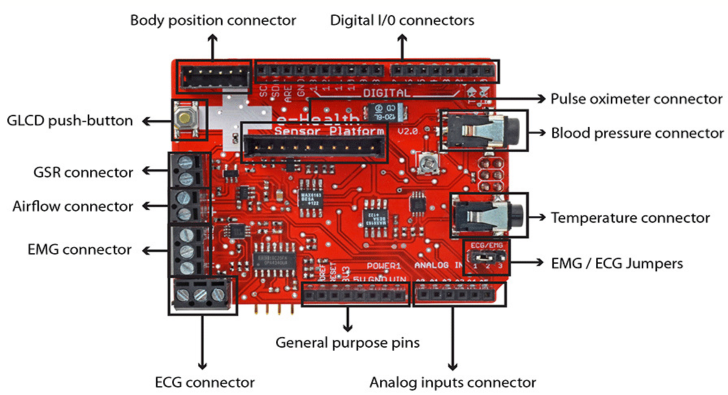


Figure 3. The biometric shield

After investigating all of the above mentioned alternatives we decided to use the e-Health Sensor Platform V2.0 for Arduino and Raspberry Pi (Biometric / Medical Applications) based solution because this solution is matched with our system objectives. While choosing this solution we consider the following design issues: (a) we need to input the data through the mobile devices, (b) we can acquire ten different data using this kit, and (c) we need to connect different sensors in this project.

4. SYSTEM COMPONENTS

In addition to the e-Health Sensor Platform we used the following components to implement this system: (a) ECG electrodes, (b) temperature sensor (LM35), (c) blood pressure sensor, (d) blood glucose sensor, and (e) Microsoft Surface Pro Tablet.

A.ECG Electrodes

An ECG electrode is a device attached to the skin on certain parts of a patient's body — generally the arms, legs, and chest — during an electrocardiogram procedure. It detects electrical impulses produced each time the heart beats. The number and placement of electrodes on the body can vary, but the function remains the same. The electricity that an electrode detects is transmitted via this wire to a machine, which translates the electricity into wavy lines recorded on a piece of paper. The ECG records, in a great detail, are used to diagnose a very broad range of heart conditions. An ECG electrode is usually composed of a small metal plate surrounded by an adhesive pad, which is coated with a conducting gel that transmits the electrical signal.

B. The LM35 Temperature Sensor

The LM35 series are precision integrated circuit LM35 temperature sensors, whose output voltage is linearly proportional to the temperature in Celsius (Centigrade). The LM35 sensor thus has an advantage over linear temperature sensors, calibrated in °Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient centigrade scaling. The LM35 sensor does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full -55 to +150°C temperature range. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air.

C. Blood Pressure Sensor

Blood pressure sensor is a device that measures the pressure of the blood in the arteries as it is pumped around the body by the heart. When our heart beats, it contracts and pushes blood through the arteries to the rest of our body. This force creates pressure on the arteries. Blood pressure is recorded as two numbers—the systolic pressure (as the heart beats) over the diastolic pressure (as the heart relaxes between beats). Some special features of blood pressure sensor includes (i) automatic measurement of systolic, diastolic and pulse, (ii) large LCD screen with LED backlight, and (ii) touch pad key. In addition a typical blood pressure sensor can store 80 measurements data with time and date.

D. Blood Glucose Sensor

Blood glucose sensor is a medical device for determining the approximate concentration of glucose in the blood. A small drop of blood, obtained by pricking the skin with a lancet, is placed on a disposable test strip that the meter reads and uses to calculate the blood glucose level. The meter then displays the level in mg/dl or mmol/l.

E. Microsoft Pro Tablet

A tablet computer is a mobile computer with display, circuitry, and battery in a single unit. Tablets are equipped with cameras, microphone, accelerometer, and touch screen with finger or stylus gestures replacing computer mouse and keyboard. Tablets include physical buttons to control basic features such as speaker volume, power, and ports for network communications and to charge the battery. An on-screen pop-up virtual keyboard is usually used for typing.

In addition to these components we used ZigBee wireless technology and LabVIEW software to implement the system. The combination of ZigBee wireless technology and the LabView software has made our system cost effective, scalable, reliable, and secured as explained bellow.

5. WHY ZIGBEE AND LABVIEW COMBINATION?

The ZigBee technology was introduced by the ZigBee Alliance [24,25]. This technology has evolved based on a standardized set of solutions called 'layers'. The ZigBee was built on top of IEEE 802.15.4 standard [25]. The IEEE 802.15.4 standard defines the characteristics of the physical and Medium Access Control (MAC) layers for Wireless Personal Area Network (WPAN). Taking this standard as a "chassis" the ZigBee Alliance has defined the upper layers in the ZigBee standard. We choose ZigBee wireless technology because it has been optimally designed to provide some advantages namely low cost, low power, easy implementation, reliable, and high security. While implementing the system we consider several other wireless technologies namely Bluetooth, IEEE 802.11b, IEEE 802.11g, and UWB. The performance comparison of these technologies is presented in Table 1. The table shows that ZigBee wireless technology is a low cost and low power solution compared to other technologies. One of our design considerations was to maximize the operating life of our system. It is depicted in Table 1 that we can expect an extended life for our system because of the low power consumption of the ZigBee Technology. The transmission range of ZigBee is greater than Bluetooth, but it less compared to other technologies. Still, it is remarkable for a low power solution. While implementing any wireless health monitoring system we need to consider security issue. The ZigBee technology provides enough security for our system. The security has been ensured via several steps namely key establishment, key transport, frame protection, and device authorization. The ZigBee technology has designated a full function device (i.e., coordinator) as the 'trust center', which stores all the keys for the network. Once assigned by the 'trust center' both originator and recipient need to share the same key to ensure secured delivery of information.

Table 1: Comparison of ZigBee with other technologies

Parameter	**ZigBee**	**Bluetooth**	**802.11b**	**802.11g**	**UWB**
Throughput(Mbps)	0.03	1-3	11	54	200
Max. Range (ft)	75	30	200	200	30
Bandwidth (MHz)	0.6	1	22	20	500
Price (USD)	2.0	3.0	5.0	12	7

Another major advantage of our system is that we used LabVIEW software to design the front panel. It is an excellent integrating platform for acquiring, processing, and transmitting the physiological data. We choose LabVIEW for our projects because of the following reasons:

- It is user friendly software that helps us to program by wiring together graphical icons on a diagram that can be easily compiled directly to machine code so that a computer processor can execute it.
- It can model and analyze a large data set generated from a variety of measurements coming from sensors and data acquisition systems.
- It helps us to focus on deign instead of worrying about the low-level software and hardware issues.
- It provides very strong data acquisition tools, data analysis tools, and data visualization tools.

- It can combine mathematical equations and algorithms with online real-time measurements of real world signals.
- It provides drivers at no cost so that digital communication ports (i.e., Ethernet and/or USB port) can be used to interface with the applications.
- It offers easy and seamless integration with legacy and traditional standalone instruments.

The LabVIEW software also includes a number of advanced mathematical blocks for functions such as integration, filter, and other specialized capabilities. By using the LabVIEW we can automatically store the physiological data of patients in spread sheet, which was one of the key features for us. Based on the stored data we implement some unique features like sending an SMS to alert doctors and publishing the data in the internet so that the doctors can access them from anywhere and at any time.

6. SYSTEM OPERATIONS, RESULTS, AND VALIDATIONS

The system operating procedure is as follows:

1. We place three electrodes of ECG on the patient's body (i.e., right hand, left hand and right leg as shown in Figure 4).
2. We connect the Arduino Shield with a temperature sensor, a blood pressure sensor, and a blood glucose level sensor.
3. From the Arduino shield we connect a wireless node (as a transmitter) and the USB port of the tablet (as a receiver) or the smartphone that has LabVIEW software running on it to take the reading of the physiological data from the patients' body. The data are then processed and displayed on LabVIEW front panel by using Data Dashboard application.
4. The data are also saved according to the time and presented in a report format. In addition some personal details of the patient are also recorded.
5. The data is then published in the internet so that the patient's data can be accessed by the authorized healthcare personnel from anywhere at any time.

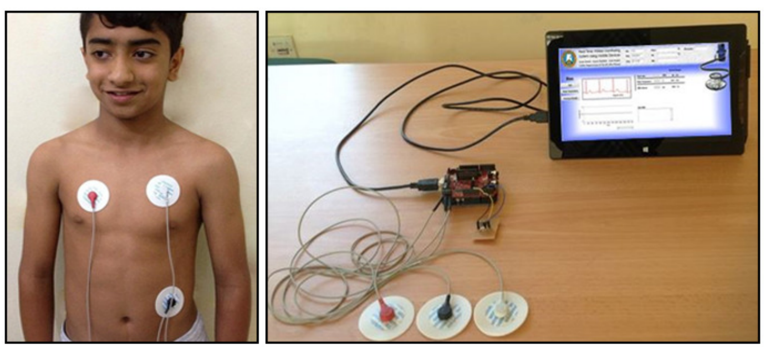


Figure 4. ECG Electrodes placements

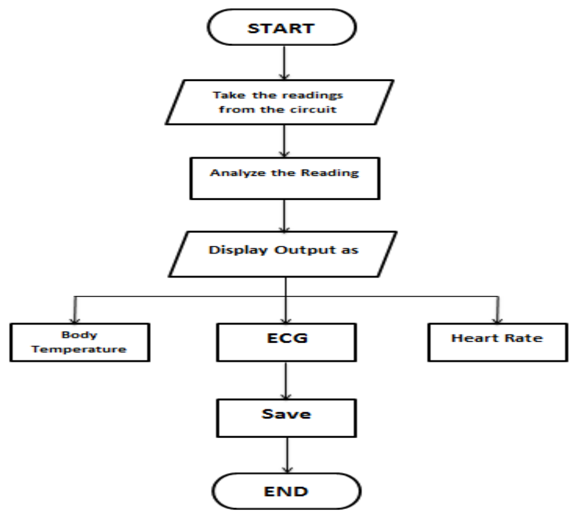


Figure 5. The Program Flowchart

After completing all the procedure the collected data can be used to monitor (in real time) the state of a patient or to get sensitive information in order to be subsequently analyzed for medical diagnosis. Biometric information gathered can be wirelessly sent using any of the six connectivity options available namely Wi-Fi, 3G, GPRS, Bluetooth, 802.15.4, and ZigBee depending on the application. In our work we use ZigBee. If real time image diagnosis is needed, the system can also be equipped with a camera attached to the 3G module. Data is sent to the Cloud in order to perform permanent storage or to visualiz in real time by sending the data directly to a laptop or a smartphone. The iPhone and Android applications have been designed in order to easily see the patient's information.

The program flowchart (see Figure 5) shows the steps of the program for the system. The program starts by receiving the readings from the sensors connected to the patient's body through wires. The acquired data is then sent to the programming environment (i.e., LabVIEW Software). The program analyzes and displays the data regarding the body temperature, ECG and heart rate. Finally, the data are saved and are also used to generate well-organized report by the system with respect to the time. The complete flowchart can be found in Appendix A of this paper. The front panel of the system is shown in Figure 6. It presents data regarding current day, date and time, ECG signal, QRS interval, heart Rate, blood pressure, and body temperature. A button located in the front panel can assist in retrieving previous data. This button is also linked to Microsoft word program to tabulate the previous results in an organized report that enables doctors and caregivers to follow patient's health status for the previous periods.

There are also buttons for ECG signal, heart rate, blood pressure, QRS interval, and body temperature. These buttons will change their color depending on the health status of a patient. For example, the button will change color from 'gray' (as originally set) to 'green' if the monitored data are within the normal range. The button will change color from 'gray' to 'blue' if the monitored data are abnormally low. Similarly, the button will change color from 'gray' to 'red' if the monitored data are abnormally high. By tracking the colors of the buttons the patient will be easily aware of her/his health status.

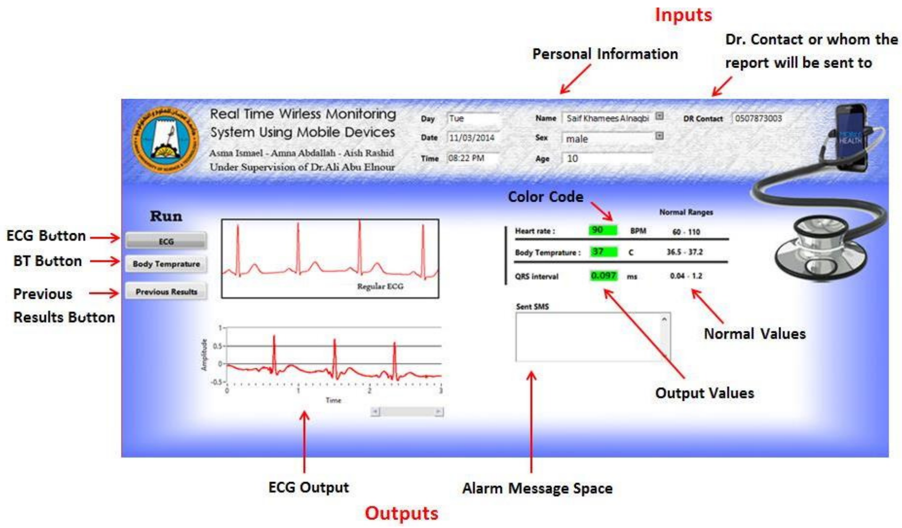
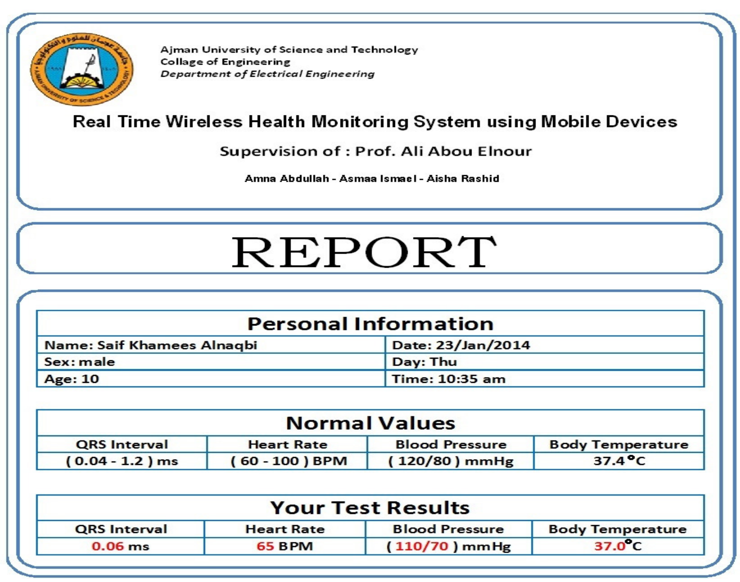


Figure 6. The front panel of the program

A sample report of a patient is shown in Figure 7. In addition to some personal information of the patient and timing data the report presents the monitored physiological data. It is depicted in the report that the heart of the patient is in normal condition. The other data including blood pressure and body temperature are also in the normal range. In order to check the reliability and validity of our system accuracy, we went to one of the local hospitals and we compared the performance of our system with that of the existing system of the hospital. We conducted test experiment on one of the patients with heart disease there. The ECG signal generated by the hospital's existing system is shown in Figure 8 and the same generated by our


Ajman University of Science and Technology
Collage of Engineering
Department of Electrical Engineering

Real Time Wireless Health Monitoring System using Mobile Devices

Supervision of : Prof. Ali Abou Elnour

Amna Abdullah - Asmaa Ismael - Aisha Rashid

REPORT

Personal Information	
Name: Saif Khamees Alnaqbi	Date: 23/Jan/2014
Sex: male	Day: Thu
Age: 10	Time: 10:35 am

Normal Values			
QRS Interval	Heart Rate	Blood Pressure	Body Temperature
(0.04 - 1.2) ms	(60 - 100) BPM	(120/80) mmHg	37.4°C

Your Test Results			
QRS Interval	Heart Rate	Blood Pressure	Body Temperature
0.06 ms	65 BPM	(110/70) mmHg	37.0°C

Figure 7. Generated Report

system in shown in Figure 9. We recognized that we obtained the same results of ECG signal and heart rate (i.e., 98 beats per minutes) from both systems. But, we discover some noise associated with the ECG signal generated by our system. This noise was generated by the electronic components used in our system as well as other existing electronic and electrical components in the hospital.

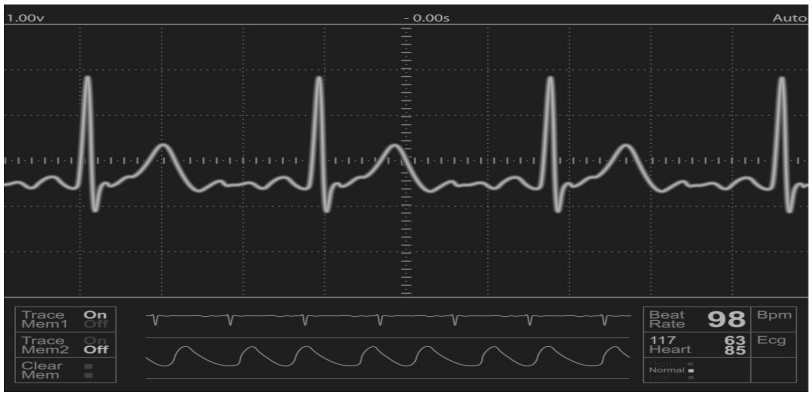


Figure 8. The data generated by the existing ECG machine

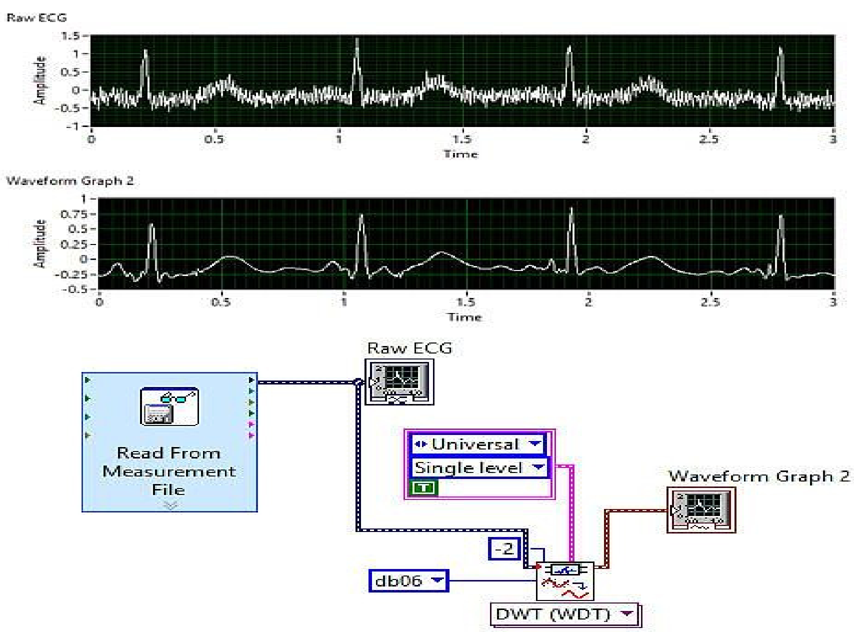


Figure 9. The ECG signal generated by our system with the Gaussian noise removed

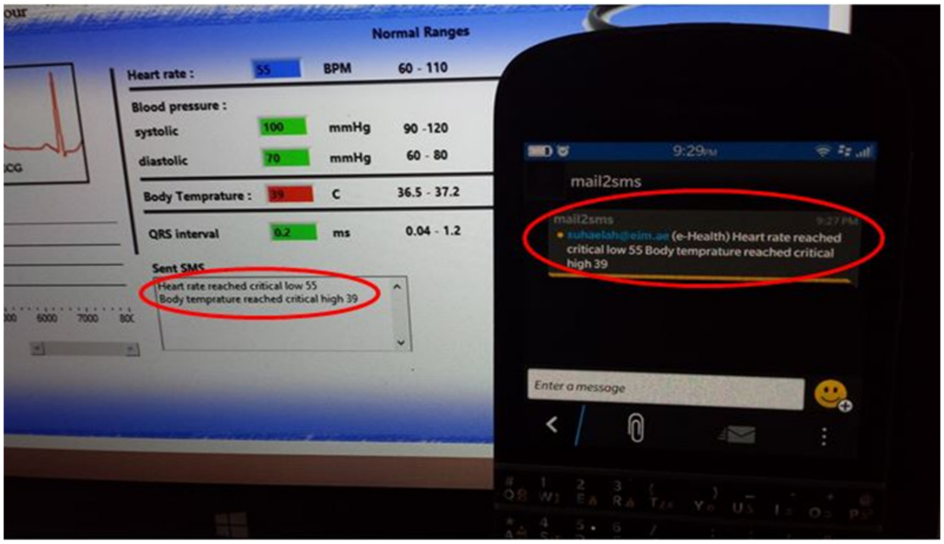


Figure 10. Generating alert messages

Obviously, the noise generated associated with our system is a low pass Gaussian noise. We remove the noise by using a special low pass filter. We designed this low pass filter by using Kaiser Window in LabVIEW and the filtered ECG signal is also shown in Figure 9. Comparing this filtered ECG signal with that shown in Figure 8 we conclude that our system now generates same ECG signals with minimum error. Our system generates alert message when the monitored physiological data of patients are outside the normal set ranges. This type of alert message generation is illustrated in Figure 10. This figure depicts that the body temperature of the monitored patient is outside the set normal range. The body temperature button on the front panel (see Figure 10) turns red. The system generates an alarming SMS as shown in the front panel and sends the SMS to a smart phone as shown indicated in the display of the phone.

6.CONCLUSIONS

A smartphone based health monitoring system has been presented in this work. By using the system the healthcare professionals can monitor, diagnose, and advice their patients all the time. The physiological data are stored and published online. Hence, the healthcare professional can monitor their patients from a remote location at any time. Our system is simple. It is just few wires connected to a small kit with a smartphone. The system is very power efficient. Only the smartphone or the tablet needs to be charged enough to do the test. It is easy to use, fast, accurate, high efficiency, and safe (without any danger of electric shocks). In contrast to other conventional medical equipment the system has the ability to save data for future reference. Finally, the reliability and validity of our system have been ensured via field tests. The field tests show that our system can produce medical data that are similar to those produced by the existing medical equipment.

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Appendix A : Complete Flowchart