Real-Time Patient Health Monitoring and Alarming Using Wireless-Sensor-Network

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***Abstract*—The main objective of this research is design and realization of real-time monitoring and alarming system for patient health, especially for patients suffering from diseases during their normal life. The proposed system has an embedded microcontroller connected to a set of medical sensors (related to the patient case) and a wireless communication module (Bluetooth). Each patient is considered as a node in a wireless sensor network and connected to a central node installed at the medical center through an internet connection. The embedded microcontroller checks if the patient health status is going well or not by analyzing the scanned medical signals. If the analysis results are abnormal, the embedded unit uses the patient's phone to transmit these signals directly to the medical center. In this case, the doctor will send medical advice to the patient to save his/her life. The implemented prototype has been tested and calibrated with standard devices. The experimental results confirm the effectiveness of the proposed system that is accurate in scanning, clear in monitoring, intelligent in decision making, reliable in communication, and cheap (about 100 US$).**

Keywords—Health care; Patient monitor; Remote device; Biomedical device; ECG monitoring; Outdoor patient monitoring.

I. INTRODUCTION

Advances in computer and communication technologies give electronic healthcare a great opportunity to design monitoring and alarming units that can be integrated with mobile phone[1,2]. Recently, wireless sensor networks have been adopted for real-time monitoring and alarming in healthcare applications. Therefore, it is useful to integrate medical sensors, embedded systems and smart phone to design an embedded system to provide patient, doctor and medical center with real-time health information to save time, cost and life [3-5].

Wireless communication technology is considered the best way to deal with emergency situations, especially those related to the human life, where patient's health records such as previous medication history, identification and other information are necessary[6,7]. Most mobile phones and personal computers are integrated with wireless network, therefore, it is useful to use these devices for medical data transfer. In this case, "the amount of time the doctors need to identify the problem, trace back the medication history of the patient and consult fellow doctors will be reduced significantly"[7]. Such a system requires to update the databases for patients by real-time sensing and monitoring of their health parameters. Using computers and wireless technology in healthcare monitoring will achieve many goals, such as diagnosis time, accuracy, number of patients, amount of paper work and many others. Applications of wireless sensor technology for healthcare monitoring enable doctors to monitor their patients anywhere and at any time without any physical constraints and without the need for the patient to stay in hospital.

Real-time measurement of health parameters of critically ill patients such as heart rate, blood pressure, blood-oxygen saturation, temperature, and many other parameters have become a common feature of the healthcare monitoring system. There are many monitoring systems in medical centers used to collect and monitor patient's health. The health data are then used by doctors to generate the suitable decision. Critically ill patients require accurate monitoring and alarming system during their normal life. Therefore, it is useful to integrate the monitoring unit together with wireless sensor technology to fellow up the patient's status outside the intensive-care unit (ICU) in the hospital[2,4]. In this case, the wireless monitoring system can be modified to provide the patient through his/her phone with accurate and immediate medical treatment decisions to save patient life.

Chung and his group[8] proposed WSN-based mobile healthcare monitoring system with ECG and

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blood pressure measurement, where the mobile phone performs continuous data analysis and then transmits data over a wireless sensor network. In today's critical care environment, regardless of your age, disease or condition. it is very likely that you will receive the same type of patient monitoring. This traditional monitoring can include ECG leads that record cardiac rhythm and heart rate and SpO_2 probes that capture blood oxygen saturation levels along with other vital sign measurements [9,10]. This is mainly because these general parameters are the bone for the physician to know what to do in general. However, the fast change of health parameters is the big challenges, especially when the patient is outside home doing any usual activity and feels something wrong, and when arrived the hospital for testing, they find that everything is normal. In fact, it is not easy to detect all kinds of abnormal activity unless real-time monitoring, which can be done either by keeping the patient in the hospital for few days or more (which will of course lead to high costs). In such a case, a wireless real-time portable monitoring device can be used to help the physician and the medical center to give proper medical treatment and procedures.

It is so important to integrate low-power electronic devices, such as sensors and a microcontroller, with wireless communication technology to open new research trends in healthcare applications. The main objective of the project is to design and implement a real-time monitoring system for healthcare applications. The system is based on a single-chip microcontroller equipped with set of sensors and wireless communication unit.

Most of the e-health monitoring systems are offline units based on personal computers or smart phones used to send patient's health data to the health centers. In this research, the patient's cell phone is used to transfer real-time medical information between patients and medical center. The following section outlines the general overview of the proposed system. Section 3 discuses the detailed hardware and software design, while section 4 illustrates the procedures of the prototype testing and calibration. Finally, a fruitful conclusion and future work are listed.

II. OVERALL SYSTEM ARCHITECTURE

The general layout of the whole system architecture is given in Fig.1. It is composed of an embedded sensing unit, a personal server (patient's smart phone or PC), a medical center server and a reliable wireless communication channel.

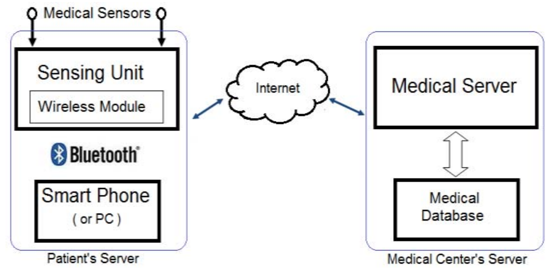


Fig.1: Healthcare monitoring system.

A. Embedded sensing unit:

It is a microcontroller interfaced with sensors and Bluetooth module for wireless communication with smart phone of the patient. The smart phone can be used to achieve wireless communication with the medical center through the internet. Direct communication can be achieved between the patient and his/her authorized doctor. The doctor can communicate with the patient medical case through the internet.

B. Patient server:

The patient server receives biomedical data from the embedded sensing unit through Bluetooth wireless channel. The patient server offers a wireless communication channel between patient and the medical center server. It performs the following tasks;

- setting initial parameters for the system, and the patient.
- collecting measured data and biomedical status from the embedded sensing unit.
- offering real-time display for biomedical measurements and medical guidance sent from the doctor.

C. Communication and security strategies:

Real-time signals from medical sensors will be sent to the mobile phone via Bluetooth connection. Then it will be redirected to internet database via 3G/4G connection. Advanced wireless security techniques shall be applied such as using SSH secure connections to internet[9,11,12], protecting database with passwords and filtering access to it via mac address, all beside using special VPN and proxy to access information, all these security layers are here only to protect patient privacy. In order to track a patient, a mobile phone integrated GPS system should be used. GPS data are secured and can't be accessed via anybody except the patient himself and the corresponding person in the medical center.

D. Power supply unit:

Monitoring and processing of real time parameters received from the embedded sensing unit via BT, and accessing real time GPS location and send everything via 3G/4G connection to internet, will consume a lot of energy. Therefore, a portable battery is required to provide enough energy for portable system beside charging mobile phone for 10 hours continuous.

III. MEDICAL SENSORS

For embedded healthcare monitoring system design, small, reliable, and low power medical sensors should be considered. The number and type of the medical sensors are depending on patient health state. As shown in Fig.2, typical medical sensors were selected, as given in Table I, these sensors are;

- Blood pressure
- Temperature
- Oxygen percentage in blood: finger-clip pulse oximeter measures both the level of oxygen saturation (SpO_2), and the heart beat rate.
- ECG signals.

TABLE I: SENSOR CHARACTERISTICS.

Measured Variable	Signal Range	Frequency Range
Heart beat rate	45-200 beats/min	Up to 100 Hz
Breathing rate	12-40 breaths/min	Up to 20 Hz
Blood pressure	40-300 mmHg	Up to 60 Hz
Temperature	20-50 Celsius	2 Hz
Electrocardiograph (ECG)	0.01-5.0 mV	0.05-100 Hz

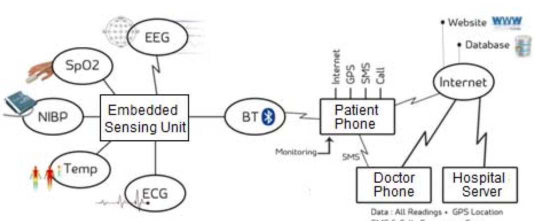


Fig. 2: Layout of the system architecture.

A. Blood pressure sensing:

The Honeywell ASDX 015PDAA5 pressure transducer has been used to measure the blood pressure. It offers ±2.0% accuracy and consumes 2mA typically. The pressure transducer is connected to a DC motor and a dump valve through an air pipe. The dump valve is directly connected to the controller, while the DC motor is connected to the controller through 2N3094 transistor, as shown in Fig. 3.

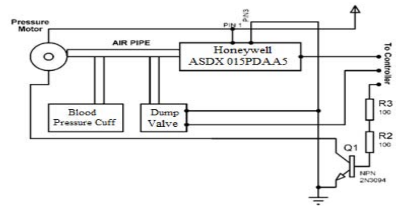


Fig 3: Blood pressure sensing circuit.

B. Temperature Sensing:

A body temperature sensor type (LM35) has been selected in the design. The sensor is connected to an amplification circuit to ensure output voltage up to 5V, as shown in Fig.4. The amplified signal is scanned by the microcontroller to measure human body temperature.

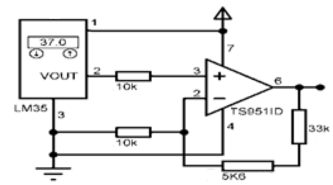


Fig. 4: Temperature sensor circuit design.

C. Heart rate and Oxygen sensing:

As the blood passes through the finger, it carries along red blood cells and their associated Hemoglobin groups. These Hemoglobin groups can absorb energy of various wavelengths of light, depending on whether the Hemoglobin is oxygenated (absorbs more infrared light) or deoxygenated (absorbs more red light), as illustrated in Fig.5. It is easier to measure how much light is transmitted through the blood (and finger) and utilize the inverse relationship that exists between absorption and transmission, i.e. if blood absorbs more IR light, then it will transmit relatively less IR light and more red light[13].

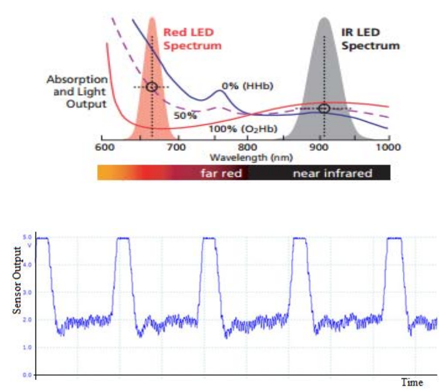


Fig. 5: Principles of SpO2 sensor.

An optical sensor is selected to measure the alteration in blood volume at fingertip with each heartbeat. It consists of an infrared LED and photodiode, both placed side by side where human fingertip goes between both. "The infrared diode transmits infrared light into the fingertip, and the photodiode senses the portion of the light that is reflected back. The intensity of reflected light depends upon the blood volume inside the fingertip. Each heartbeat slightly alters the amount of reflected infrared light that can be detected by the photodiode. The little change in the amplitude of the reflected light can be converted into a pulse"[13].

D. ECG Sensing:

The ECG sensor electrode detects the signal and converts it to an electrical signal with amplitude varies from 1 mV to 5mV. The implemented ECG unit has 5 electrodes (RA, RL, LA, LL and V1) attached to the human body at selected positions[9], as illustrated in Fig.6. A signal conditioning circuit is required to filter and amplify the analog signal generated from the ECG sensor electrode. The circuit consists of an instrumentation amplifier, low pass filter (with cutoff frequency of 150Hz), and gain amplifier, as illustrated in Fig.7.

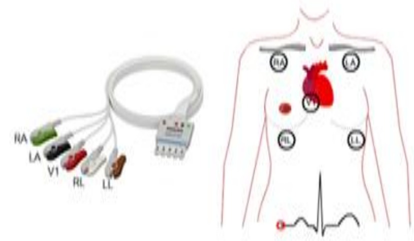


Fig. 6: The ECG leads positions on human body.

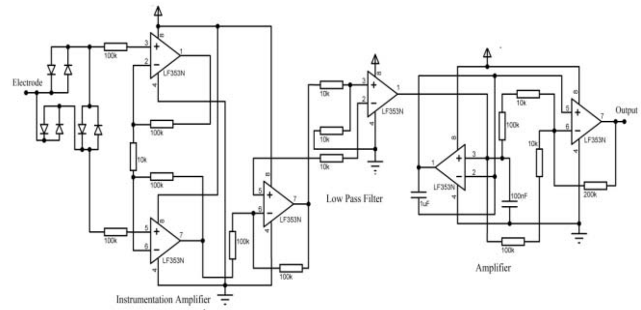


Fig. 7: ECG signal conditioning unit.

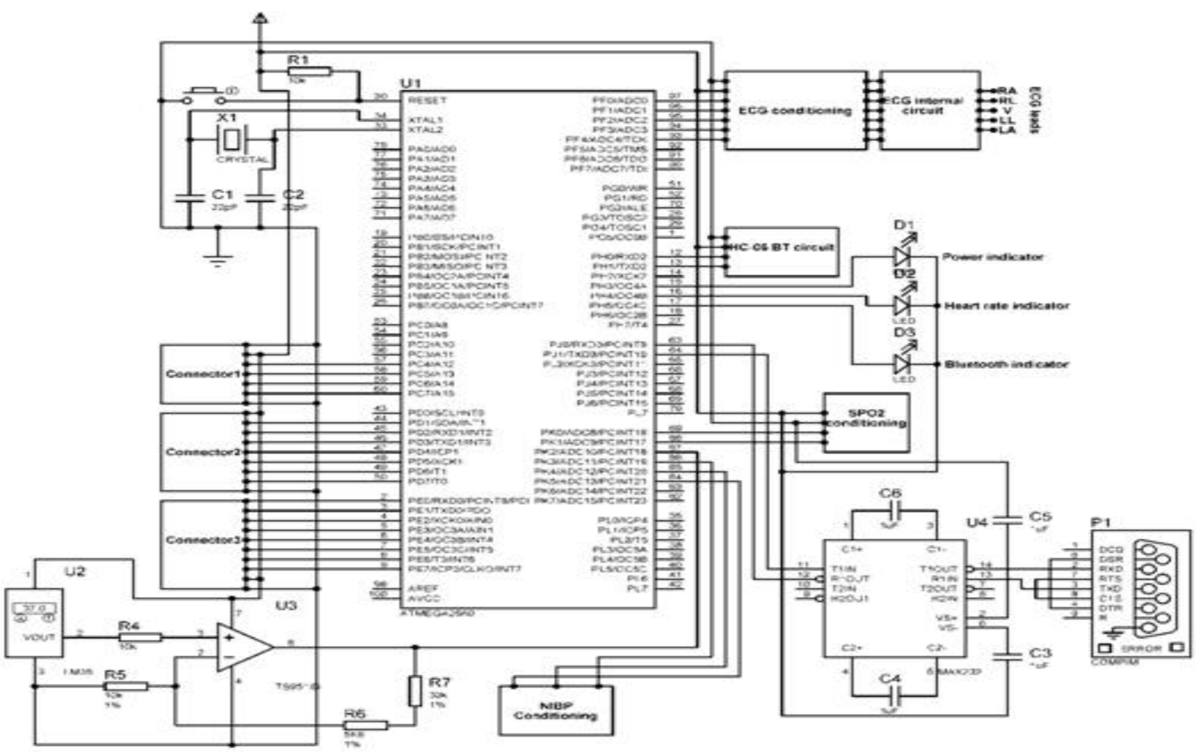


Fig. 8: Hardware design of the embedded sensing unit.

IV. SYSTEM DESIGN

The healthcare monitoring system consists of four main components, these are; sensors, microcontroller, smart phone, and the central server. The patient's smart phone has ability to transmit real-time scanned data to the medical center server. The doctor can access patient medical data directly from the medical center server through smart phone or a personal computer connected to the internet.

A. Hardware Design:

For the implemented system, four sensors are selected and interfaced to a microcontroller connected to the patient's smart phone through a Bluetooth module. According to the system design requirements, the Atmel Mega2560 microcontroller has been used in the system realization. The microcontroller is connected with BT module for wireless communication with patient's smart phone. As illustrated in Fig.8, five analog pins are used for ECG sensors, two serial pins for BT communication, three digital pins for user LED's, two analog pins for SpO_2 sensor, two serial pins for serial communication with PC, three Analog pins for blood pressure sensor, single analog line for temperature sensor and 19 pins for external connectors (for future use).

B. Software Design:

The software is divided into three main parts; the embedded microcontroller software, the patient phone software, and the medical center server software.

1). Embedded unit programming module:

This module has two procedures; the main program and the interrupt service routine, as shown in Fig.9. The main program starts by initializing I/O ports, registers, and activating Bluetooth communication that will start waiting for mobile phone connection. Hardware fault detection will make sure that there is no startup fault in the system, otherwise it will start a buzzer sound to notify user that an error exists and it will hang. If startup process is done normally without any faults then Timer 0 is assigned to work as real time clock for the system. The system will stay in standby mode waiting for interrupt or user requests for either new setting command or as calibration command which will start calibration process for required sensor.

When an interrupt occurs, the interrupt service routine will read temperature, ECG and SpO_2 sensors based on their sampling rates. Then the microcontroller may do blood pressure test if it is requested by user. Now, if 15 seconds passed and there is enough data from SpO_2 sensor, the microcontroller will calculate heartbeat rate. According to the given flowchart the measured and calculated data will be sent via BT.

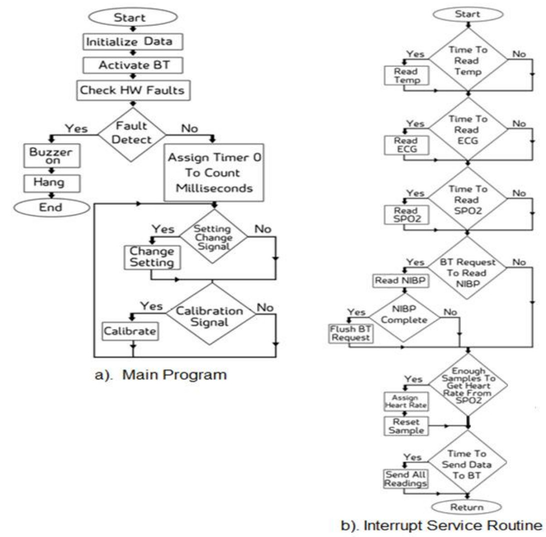


Fig. 9: Software design flowchart.

The data packets sent via BT from the embedded sensing unit to the patient mobile contains a header, sensors readings and checksum to check if data are correct or not. While command packets sent via BT from patient mobile to the embedded sensing unit contains a header, command needed (such as change parameter, calibrate sensor, measure blood pressure, etc) and a checksum to check if data are correct or not.

This method of programming is called forward/backward programming because it depends on two layers where important actions shall be made at specific time, while others (least important actions) are left in main loop and made only when microcontroller has enough free time to do them.

2). Patient phone programming:

This program module mainly consisted about having Bluetooth connection with the hardware device, friendly GUI, and internet connection to connect to database besides having access to SMS and GPS locations when they are needed. The mobile sends commands such as calibration and parameters change serially via Bluetooth to the hardware device in fixed speed of 9600 bit per second. It also receives data packets the same way and decodes them, compare them with normal values that has been set by the hospital in order to detect abnormal activity. Then, it sends these data to internet database by making a connection between server and client, entering previously stored URL, username and password beside connection port. Once connected it uses AsyncTask technology to send packets to the database via SQL and PHP commands.

3). Medical center server programming

In order to be able to create and access online database, a server is needed. A domain on a host has been used for testing purposes, and a database has been created using PHPMyAdmin that is accessible through http://host/phpmyadmin. The database has a good GUI built on PHP and can be queried via MySQL, as illustrated in Fig.10.

V. MEDICAL PARAMETERS CALCULATION

The embedded microcontroller is used to calculate the medical parameters of the patient from the measured signals. In this research, the calculated parameters are blood pressure, heartbeat rate and ECG periods to specify the heart activity.

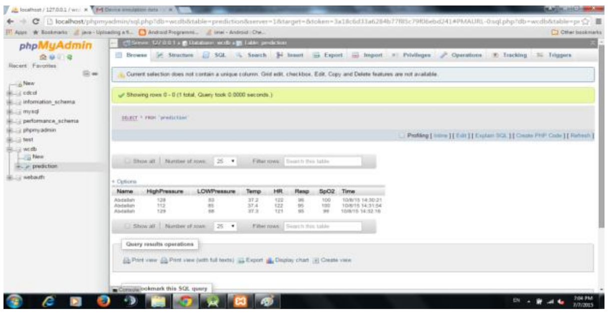
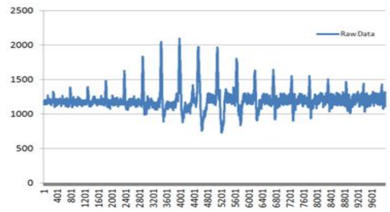


Fig. 10: Biomedical parameters on medical center's server.

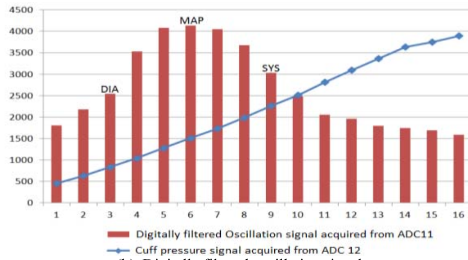
A. Blood Pressure Calculation:

To calculate blood pressure, the microcontroller closes dump valve to allow blood pressure (BP) to be inflated to 200 mmHg (as default and can be changed in settings). The microcontroller records initial pressure, then it opens and closes dump valve to deflate cuff in approximately 10 mmHg and record pressure in each interval. When cuff pressure reaches 60 mmHg, there will be enough data for software to determine mean arterial pressure. The calculated MAP is transmitted via Bluetooth to the mobile phone and cuff is deflated all the way at the end of test.

The oscillation in the pressure sensor signal is used to calculate the pressure after processing, as illustrated Fig. 11. The red graphs show digitally filtered oscillation that has been taken from analog input, while cuff pressure has been measured from another analog input. When high pressure is reached, oscillation starts since at that pressure blood starts entering hand causing oscillation, and when low pressure is reached, oscillation stops since we reached minimum pressure where we can sense blood in the hand. High and low pressure readings can be obtained by comparing oscillation values with cuff pressure. The high pressure is cuff pressure when oscillation starts above threshold value, while the low pressure is cuff pressure when oscillation is drops under threshold value. As illustrated in Fig.12, the controller makes sure that cuff has been inflated completely, then it enables ADC interrupt to take samples when needed. Then, the motor starts and flats cuff to 300 mmHg as default and bump starts to inflate cuff by 100 mmHg each time.



(a). Raw sampled data of pressure sensor.



(b). Digitally filtered oscillation signal.

Fig. 11: Blood pressure measurement.

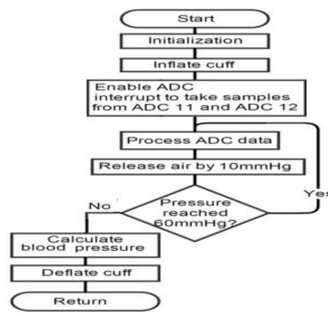


Fig. 12: Blood pressure measurement flowchart.

The controller keeps processing ADC values until air pressure in cuff reaches 60 mmHg. Then actual high and low blood pressure values are calculated depending on ADC samples, and cuff is completely deflated.

B. Heartbeat Rate Calculation:

The output pulses generated from the SpO_2 sensor are used by the microcontroller to calculate the heart rate of the patient. The sampling rate of the counted pulses is 15 sec, then the counter content is multiplied by 4 to measure number of heartbeat per minute (bpm).

C. Normal ECG Parameters:

A typical ECG signal is characterized by five points (P, Q, R, S, and T) and consists of three main waves; PR interval, QRS duration, and QT interval, as given in Fig.13. In the normal state of the heart, the normal ECG signal has the following[14,15]:

- Heartbeat rate: 60-100 bpm.
- The PR Interval: 120-200 msec.
- The P wave: less than 100 msec. width and 0.25 mV height.
- The QRS duration: 40-100 msec.
- The QT interval: less than 400 msec. in males and less than 450 msec. in female.

It is mentioned in literature [14,16,17] that the detection of the QRS duration is the most important issue in automatic ECG analysis. Several methods and algorithms for automated ECG feature extraction have been developed. In this paper, a simple detection algorithm based on real-time calculation of the QRS duration has been used to decide whether the heart activity is normal or abnormal. Such algorithm is insufficient and requires more features to be extracted from the ECG signal. This will be modified in the second stage of the project.

VI. SYSTEM CALIBRATION AND TESTING

The implemented monitoring and alarming system has been tested to make sure that all components work properly. The system hardware and software has been initially prepared, then the selected sensors were linked with the human body, as shown in Fig.14. The wireless communication channel between patient side and the medical center is achieved if the remote server at the medical center is connected to the internet. The server database involves full information about the patient including the recording of a patient's physiological parameters, such as heartbeat rate, ECG signal, blood pressure, collection of laboratory results, and assessment of a patient's health status[18].

During system testing and calibration, the following setting parameters were considered;

- Four sensors; Temperature, ECG, Heart beat rate,
- Heart beat rate: (60-100) click per minute for normal rate.
- Measuring cycle: 60 seconds.
- Normal physiological parameters setting of the patient, such as average heartbeat rate and blood pressure rates, ECG signal parameters, etc.
- The measured signals are used to calculate the critical biomedical parameters, and if it is abnormal, the microcontroller will send a request to the remote server to record the patient's health data.
- The patient can monitor his/her biomedical data using his/her phone.
- An external flash memory can be connected to the embedded sensing unit to be used as an external database.

Several experimental tests have been achieved in the medical center of Philadelphia University to check the functionality and accuracy of the implemented system. The heartbeat waveform, ECG signal, and other medical parameters generated from the implemented prototype are almost identical to what obtained generated from the recommended devices at the medical center as illustrated in Fig.14 and Table II. It is clear, that the proposed system is accurate in scanning, clear in monitoring, intelligent in decision making, and reliable in communication.

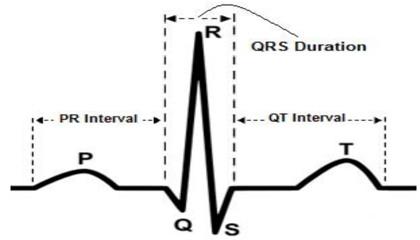


Fig.13: Main Components in ECG signal.

TABLE II: SENSOR CHARACTERISTICS.

Parameter	Implemented Device	Medical Center Device
Temperature	37.3 °C	37.3 °C
Oxygen level	93%	92%
Heart rate	88 bpm	88 bpm
Heart beat waveform	Looks Identical	Looks Identical
ECG test	Looks Identical	Looks Identical
Blood pressure (H/L)	130/91 mmHg	128/89 mmhg

The obtained results can be monitored by the patient through friendly GUI, as shown in Fig.15. It is clear, that the proposed system is accurate in scanning, clear in monitoring, intelligent in decision making, and reliable in communication, and cheap (about 100USD).


Fig. 14: Normal ECG waveform recorded from the prototype.

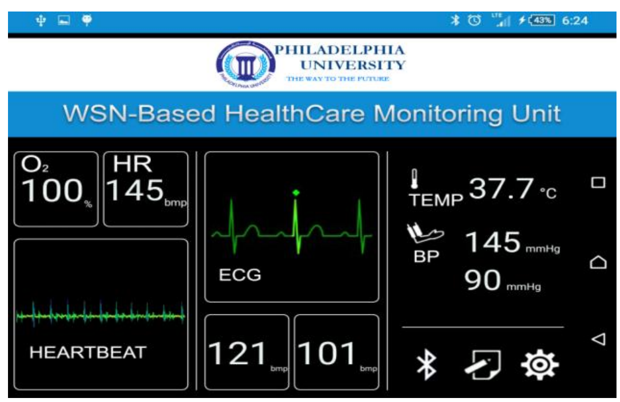


Fig. 15: The GUI monitoring on the patient's phone.

VII. CONCLUSION

The availability of low-cost single-chip microcontrollers, and advances in wireless communication technology has encouraged engineers to design low-cost embedded systems for healthcare monitoring applications. Such systems have ability to process real-time signals generated from biosensors and transmit the measured signals through the patient's phone to the medical center's server. The functionality and readings of the implemented prototype has been tested and compared with reliable, standard and calibrated medical devices in the medical center of Philadelphia University. The implemented system has the following features;

- Its functionality is similar to the normal monitoring systems used in the Intensive Care Units (ICU) at hospitals.
- It can be used as a portable device connected with patient mobile through Bluetooth communication module.
- The same device can be used as a home device connected to the internet. In this case, extra test can be achieved by the device, such as Glucose, Uric Acid, Cholesterol, and others.
- It can be used to provide a patient with medical advice according to the real-time acquired physiological data.
- Real time measuring for patient state is required in order to detect issues and solve them before disaster occurrence.
- Obtained results from real tests encourage us at Philadelphia University-Jordan to go ahead for further development and possibility of marketing in the near future.

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