DEVELOPMENT OF AN IOT-BASED PATIENT HEALTH MANAGEMENT SYSTEM

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ABSTRACT

This real time temperature and heart rate patient monitoring system is designed and developed to enhance the diagnosis of patients and the ability of medical personnel to monitor patients' health state. Owing to increasing related heart diseases in both old and young populations, an accurate, affordable and portable electronic health management device such as that developed in this work is essential for taking preventive measures. The usefulness of the device cannot be overemphasized in situations where no doctor or clinic exists nearby, and patients are unable to perceive the true state of their health. The developed system consists of an Arduino UNO microcontroller unit, the transmission unit, display unit, and biosensors. The system measures heart rate and body temperature vitals simultaneously acquired and processed on the portable device in real time, and sends the acquired information through a text message to the medical practitioner's mobile device, which ultimately enables prompt prescription. The developed system proves to be more affordable compared to some other developed health devices due to use of the easily available Arduino UNO board, ubiquitous smart Android devices, and low-price sensors. It also shows accurate and acceptable outcomes when compared with some other more traditional measuring devices.

Keywords: health parameter mornitoring, internet of things, mobile devices, biosensors, arduino microcontroller

1.0 INTRODUCTION

Most countries in sub-Saharan Africa have poor healthcare facilities, and Nigeria is not an exception. Some of the more common challenges include insufficient hospitals to measure up with increases in population, very few doctors per population distribution, and inadequacy of infrastructure, especially in terms of basic diagnostic equipment for the diagnosis of life threatening diseases, Riley *et al.* (2011); Chang *et al.* (2011).

There is this popular saying that health is wealth. Some benefits accruing from a healthy citizenry include contribution to the gross domestic product and tax revenues of a country and reduced burden on health facilities and medical professionals. Over the past decade or so, there has been intensified research into improving health care delivery using a modernized approach as opposed to traditional means. Major advancements in recent times include patient health monitoring and management systems which are deployed using popular and readily available interconnection of local wireless sensor networks (WSN), mobile devices, the internet, as well as cloud technologies, all integrating into a concept called the internet of things (IoT), Shah *et al.* (2013); Sawand *et al.* (2015); Antonovici *et al.* (2014); Moeen *et al.* (2015).

This new development removes the need for medical personnel to always be present for diagnosis of the patient, minimizes patient admissions for assessment in hospitals, and also results in the reduction of financial requirements and time as was quite common in the traditional approach Navdeti *et al.* (2016). The major interest in this medical care paradigm shift is to emphasize the benefits of self-care which ultimately focuses on prevention and early detection over curative measures, Fu *et al.* (2008); Khalil and Su (2008).

2.0 PARAMETER MEASUREMENT

The basic parameters of focus in the deployed patient health monitoring system (PHMS) are temperature and heart rate measurements.

2.1 Heart Rate Measurement

Heart rate can be defined as the number of heartbeats per unit of time. Usually, heart rate is expressed as beats per minute (BPM). Heart rates can change as the body's need to absorb oxygen and release carbon dioxide changes due to involvement in different activities such as during exercise or when at rest. A measured heart rate is deemed to be abnormal when the heartbeat is too fast, slow, or irregular. The general term used to describe this condition is arrhythmia. Medically, heart rates measuring 140 and above pose serious danger to the patient, Jevon and Ewens (2007). Measurement of heart rate is mostly used by medical professionals as a primary test to help in the diagnosis and tracking of cardiovascular diseases (CVDs). From previous researches done, it has been found that increase in heart rate over a length of time can result in serious CVDs such as tachycardia (heart rate more than 100), bradycardia (heart rate less than 60), amongst others, Nemec *et al.* (1999).

Accelerated beating of the heart is called tachycardia, and when this condition is persistent, it may be an indication of impending heart failure or cardiogenic shock. Heart rate measurement is also used by athletes who are involved in intense physical training to achieve maximum efficiency. Khalil and Su (2008) reviewed some existing reactive mobile care systems which send information on detected abnormalities in heart rates obtained from sick and elderly patients. With the deployment of the PHMS, patients likely to develop potentially fatal CVDs can be given early warning and can be properly managed to prevent the disease from attaining maturity.

2.2 Temperature Measurement

Physicians have always recognized the significance of a raised body temperature since the days of Hippocrates. The idea of thermometry was invented by Galilleo who made his famous thermoscope from a glass tube. Temperature was assessed by the rising and falling of small beads or seeds within the fluid inside the container. It is to be noted that Carl Wunderlich who developed the clinical thermometer did a lot of painstaking work on body temperature in health and disease, (Pearce, 2002).

Body temperature is usually controlled by the part of the brain called the hypothalamus which is like a thermostat for the body. It maintains normal temperature through heating mechanisms such as shivering and metabolism, and cooling mechanisms such as sweating and dilating of blood vessels close to the skin. Normal body temperature can vary depending on the individual, time of day, and weather. For most people however, a temperature of 98.6 F (37^{0}C) is baseline. Maintaining a constant body temperature is very important, and this can be easily done by measuring body temperature regularly. There are many medical reasons for fluctuating body temperature in children and adults.

3.0 EXPERIMENTAL PROCEDURE

Basically, the PHMS performs functions such as bio-signal acquisition, storage, processing, transmission and display of measured outputs. User interaction with the system is enhanced using text-based and graphical outputs delivered by means of a mobile device and a cloud-based web application. The interconnection between different components of the PHMS is illustrated in Figure 1 which represents the overall system architecture.

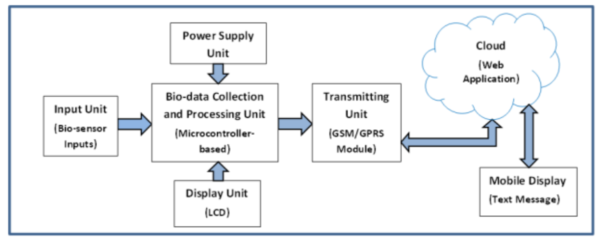


Fig. 1: PHMS System Architecture

The PHMS is made up of six major units, namely; the power supply, input, processing, transmitting, display and output units. The working principle of each unit is discussed as follows;

3.1 Input Section

The input section comprises of the pulse (heart rate) sensor (SEN-11574), and temperature sensor (LM 35). These bio-sensors are responsible for sensing and measuring the specified vitals from the human body and sending it onward to the microcontroller for further processing. The sensors used in this work were wrapped on the wrist and plug right onto the Arduino Uno board.

3.1.1 Pulse Sensor

The circuitry of the pulse sensor is composed of a sensor module which senses blood circulation and converts the measured value to an electrical signal which is further amplified and pre-processed for noise reduction. The output of the sensor in this design is a real-time analog voltage signal that swings between 0V and 5V.

3.1.2 Temperature Sensor

The LM35 series temperature sensor is a precision device with an output voltage that is linearly proportional to the centigrade temperature. It provides typical accuracies of ±¼^{o}C at room temperature, and ±¾^{o}C at temperatures ranging from -55ºC to 150ºC. The device is used with single power supplies and interfacing with readout or control circuitry is especially easy.

3.2 Data Processing Unit

This unit is implemented using Arduino Uno. Arduino Uno is a microcontroller board based on the ATmega328. The

ATMega 328 microcontroller has advanced RISC architecture with up to 20 MIPS throughput at 20MHz, 131 powerful instruction, 32 x 8 general purpose working registers, operating voltage of about 5.5V, temperature range of -40^0C to 85^0C, and a power consumption of between 0.2mA - 0.75µA.

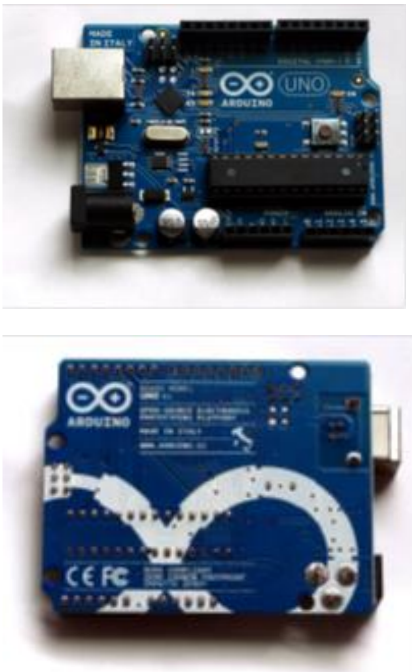


Fig. 2: Front and back view of the Arduino Uno board

The Arduino Uno board has 14 digital input/output pins (of which 6 can be used as pulse width modulation (PWM) outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It can be powered via its USB connection or with an external power supply. Some of its primary functions in the system design include control and coordination of processes, issuance of commands, processing of signals, and initiation of appropriate responses. The Arduino Uno interfaces with the input unit to receive real-time bio-information, the GSM/GPRS module housed within the transmission unit, and finally, the LCD display.

3.3 Display Unit

Here, a liquid crystal display (LCD) serves as a visual aid to display output values and messages to the patient. A sixteen by two (16×2) LCD module which can display 32 ASCII characters in 2 lines (16 characters in 1 line) is employed in this work.

3.4 Transmitting Unit

In this unit, a GSM/GPRS module is used to establish communication between the microcontroller and existing GSM/GPRS systems. Global System for Mobile communication (GSM) is an architecture used for mobile communication while Global Packet Radio Service (GPRS) is an extension of GSM services which enables higher data transmission rates. GSM system was developed as a digital system using time division multiple access (TDMA) technique for communication purpose. The digitized bio-data, which is further compressed by the GSM module, is sent through a channel with two different streams of client data, each in its own particular time slot. It conveys alert messages generated by the microcontroller to a specific mobile device and web application for feedback response and has the ability to carry data ranging from 64 kbps to 120 Mbps. The GSM module used in this project is the SIM800 - a complete Quad-band GSM/GPRS solution in SMT form. SIM800 supports quad-band 850/900/1800/1900MHz, and can transmit voice, short message service (SMS) and data information with low power consumption. Its tiny size satisfied the compact demands of the design while Bluetooth and embedded AT features provided significant cost savings.

3.5 Power Supply Unit

The Arduino board can be powered via its USB connection to a computer. Since other units of the PHMS system, apart from the output, also connect to the Arduino board, the entire system likewise gets powered at once. Alternately, the Arduino's power supply port can be connected to an external ac power supply or a dc power supply through the input pins. Similarly, leads from a battery can be inserted into the pin headers of the POWER connector. The board operates maximally on an external supply of between 7 to 12 volts.

3.6 Output Unit

The output unit consists of the web application residing in the 'cloud', and the display of the mobile device. The web application is an open-source monitoring app that graphs real time pulse rate and temperature values received through the GSM/GPRS module attached to the processor using existing cloud technologies. Likewise, the mobile device of an authorized medical personnel receives and displays measured values of the data sent through automated text messages.

3.7 Software Design

The hardware component of the Arduino board is accompanied by a software module called the integrated development environment (IDE). This piece of software was installed on a computer, and was subsequently employed to write and upload computer code to the physical board. The written program (called a sketch) thus interacts with the hardware components of the Arduino and the devices connected to it.

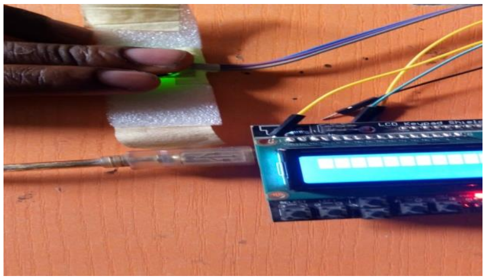


Fig. 3: Pulse sensor programming

Two modules were programmed, namely, the GSM/GPRS module and the pulse sensor. The GSM module was programmed to transfer data to the webserver and also send SMS to the required medical personnel when measured vitals are at abnormal values, while the pulse sensor was programmed to transmit bio-data obtained from the wrist to the Arduino microcontroller. The flowchart of the real time temperature and heart rate PHMS is given in Figure 4.

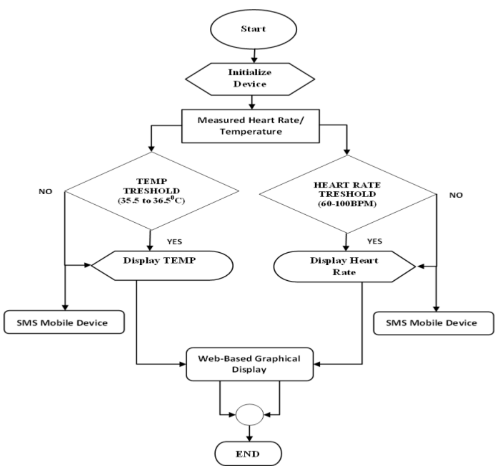


Fig. 4: Flowchart of PHMS

4.0 RESULTS AND DISCUSSION

In order to determine the performance of the developed prototype of the PHMS, an evaluation of its efficiency and accuracy was carried as compared to that of traditional devices such as the clinical thermometer and sphygmomanometer commonly used in most health facilities.

4.1 Real Time Test

A real time test was carried out to ascertain the efficiency and accuracy of the system. This test was repeated over a period of ten days with both the PHMS and traditional devices used in clinics.

(a)

(b)

(c)

Fig. 5: (a) Test patient using sphygmomanometer, (b) Test patient using clinical thermometer, (c) Vital signs measurement using bio-sensors attached to prototype

The measured values of bio-signals obtained in relation to temperature and heart rate of a test patient over a period of ten days without observance of a particular time of day or activity is presented in Tables 1 and 2 respectively. The heart rate and body temperature values were found to be changing due to the various activities the test patient was involved in and different postures assumed.

Table 1: Real Time Test Data Using Patient Health Management System (PHMS)

NO. OF TEST	HEART BEAT RATE	TEMPERATURE
1	100	36.5
2	99	35.5
3	89	36.4

4	113	37.0
5	98	36.5
6	96	36.6
7	77	36.3
8	88	35.8
9	88	35.7
10	68	35.9

Table 2: Real Time Test Data Using Sphygmomanometer and Clinical Thermometer

NO. OF TEST	HEART BEAT RATE	TEMPERATURE
1	98	36.4
2	97	35.5
3	89	36.1
4	114	36.9
5	98	36.5
6	96	36.4
7	79	36.4
8	88	35.7
9	88	35.7
10	68	35.9

Using the results obtained from Tables 1 and 2, graphs of measured values of heart rate in beats per minute as well as body temperature in degrees celsius were plotted against individual measurements over a period of ten days. This was done to better illustrate the comparative performance of the PHMS against traditional measuring instruments.

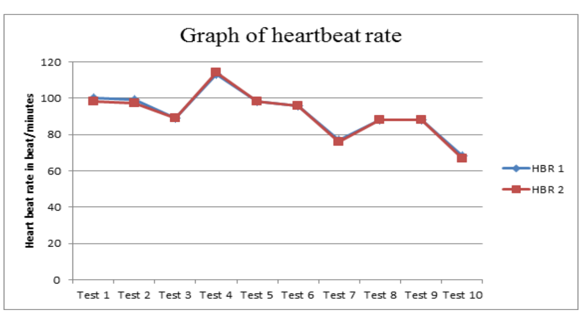


Fig. 6: Comparative plot of heart rate of test patient

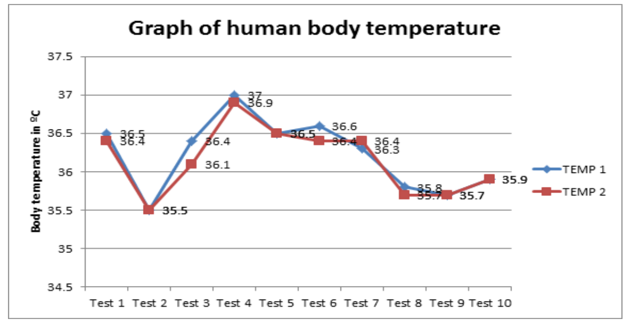
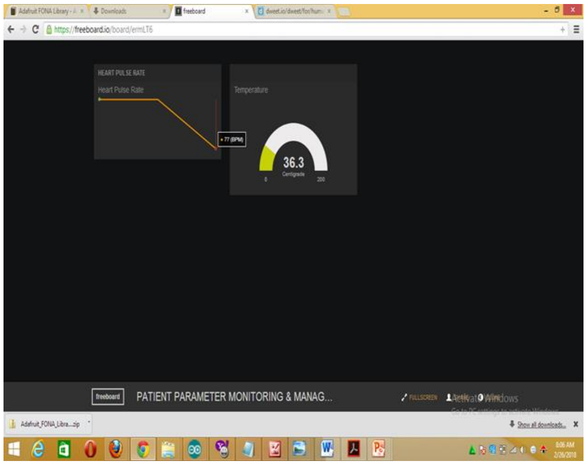


Fig. 7: Comparative plot of body temperature of test patient

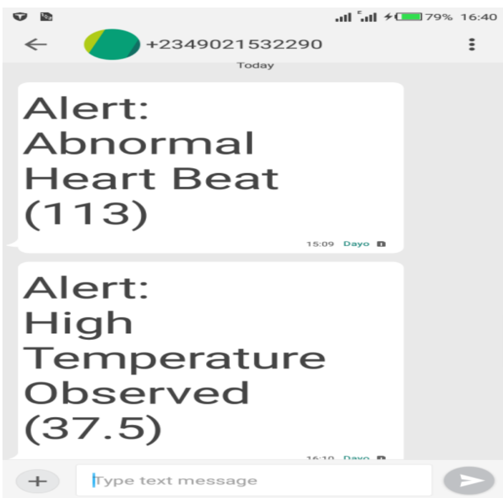
For Figures 6 and 7, the blue line depicts the plot of measured heart rate and temperature values using the PHMS while the red line represents the plot of measured heart rate and temperature values using the sphygmomanometer and clinical thermometer. In Figure 6, it can be observed that for most part, the two plots appear to be almost superimposed except at a few data points where the readings vary slightly. In Figure 7 however, the variations in the measured values at each data point are more pronounced. These differences can be allotted to circuitry and environmental effects on the constructed device. From these test results, it can be seen that the performance of the PHMS compares favourably with that of traditional health parameter measuring instruments.

4.2 Webserver and SMS Outputs

As previously stated, measured values of bio-signals obtained from the PHMS are sent to a webserver and stored for further observation. A web application is thus employed to provide a visual display of the graphed measurements. A physician or any authorized health personnel can thus logon to the web address at https://freeboard.io/board/ermLT6 for further observation of the graphed values. This is achievable when there is internet facility that will make the webpage accessible. The page will be displayed as shown in Figure 8. Using this means, medical practitioners are able to gain access to real time data of the patient at the point of test. When the value goes above the specified normal rates, then text messages are sent immediately to the health personnel for prompt action to be taken.



(a)



(b)

Fig. 8: Screen shots of (a) web-based graphical data and (b) SMS received

In Figure 9, the prototype of the developed system is shown. This comprises of the power supply module, the attached sensors, and the PHMS.

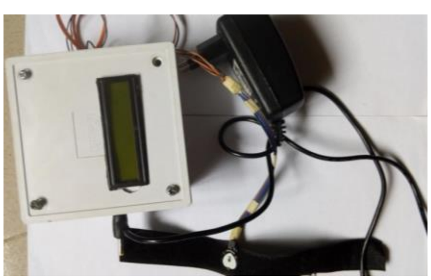


Fig. 9: Prototype of PHMS system

5.0 CONCLUSION

The developed prototype of this real time temperature and heart rate patient health monitoring system has been duly tested and its performance is seen to compare favourably with existing traditional methods of obtaining vital signals from patients using the sphygmomanometer and clinical thermometer. Bio-data is obtained by wrapping the sensing device on the wrist and the values obtained are observed by the patient on a liquid crystal display. If the displayed values are not in the range of pulse and temperature sensor thresholds, then an alert message using SMS is sent to the mobile phone of the authorized health personnel in charge of the patient, and also forwarded to a webserver for storage and viewing purposes.

The deployment of the outputs of this work on a large scale in the medical arena will be very useful since the system enables the monitoring and management of patients outside of clinical settings in any location, and can increase access to healthcare, decrease problems associated with poor diagnosis of patients, and also improve doctor-patient relationships. An additional advantage is that its use is not only limited to clinical applications, but can also be employed by healthy individuals who are interested in maintaining a good state of health. Some further implementation efforts on this work will include the creation of a database that can accommodate multiple user data collation at the webserver storage end and the development of a closed loop system to aid instant medical advice from doctor to patient.

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