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COVID-19 pandemic management: a multi-parameter portable healthcare monitoring device

Abstract

Overcrowding of patients at hospitals is among the challenges of the COVID-19 pandemic. Medical Staff are over tasked and Medical facilities are overwhelmed. Medical staff in the front line are exposed to risks. The reduction of overcrowding at Hospitals and healthcare centers with the introduction of portable systems for remote monitoring of patients using the Wireless Sensor Networks, specifically for those who are suffering from cardiac diseases is therefore an essential part of COVID-19 pandemic management. Patients with heart failure are at the highest risk during COVID-19 pandemic and the mortality rate of infected patients with heart failure is the highest. The development of a Personal health monitoring device (PHMD) for ECG display, SpO_2 and pulse rate (beat per minute) measurements is presented. An Electrocardiogram (ECG) is a graphical presentation of the heart activity over time. The graphical presentation of the ECG can be interpreted, so that normal and abnormal rhythms of the heart can be detected and diagnosed. Pulse oximetry is the non-invasive measurement of the oxygen saturation which is the percentage of SpO_2 concentration. It is used for a rapid assessment of a patient's respiratory function to determine the onset of hypoxemia (oxygen starvation) or COPD (Chronic obstructive pulmonary disease). The aim of the portable healthcare monitoring device is to continuously monitor and measure the patient vital signs in order to detect and prevent a heart attack before it occurs. The sensors convert the detected physiological parameters into electrical signals which will be processed using the digital signal processor (DSP) according to an algorithm. The processed data is transferred to the android application interfaces via serial port Bluetooth communication. The android studio further processes the received data, plots the Electrocardiogram (ECG) graph and displays the SpO_2 using algorithms written in java programming language. The android application offers data storage in a cloud server and communication between the patient and the doctor through a chat system. The developed Personal health monitoring device (PHMD) functions satisfactorily and is ready for clinical trial. The mass production of this device will reduce overcrowding of patients at the healthcare centers as monitoring which is part of patient healthcare services can be done remotely and effectively.

Keywords: COVID-19 pandemic management, heart attack prevention, telemonitoring, physiological parameters sensors, digital signal processing, android app, bluetooth communication, cloud server

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Introduction

COVID-19 pandemic challenges include overcrowding of hospitals. Medical Staff are over tasked and are exposed to risks. Medical facilities are overwhelmed.[1–4] The ratio of health workers in Nigeria numbers 0.83 physicians per 1000 patients was grossly inadequate even before the COVID-19 pandemic.[5] The ratio of health workers in other African countries is also inadequate.[5] Various measures are required to slow down the spread of the COVID-19 virus. There is also the need for the reduction of overcrowding at Hospitals and health care centers as part of COVID-19 pandemic management. Development of Portable Health Care Devices is a step in this direction. NP of portable systems for remote monitoring of patients using the Wireless Sensor Networks, specifically for those who are suffering from cardiac diseases are becoming one of the most critical fields in telemedicine.[6–8] Patients with heart failure are at the highest risk during COVID-19 pandemic and the mortality rate of infected patients with heart failure is the highest.[9–11] Remote patient monitoring, telemedicine, and telemonitoring are developing fields in medicine.[7,9,11,12] Recent studies have shown that people do not use their smartphones for communication only, but they are increasingly using them to detect and monitor their status.[13] Health care Professionals also facilitate their work with Mobile devices and apps.[13–15] NP health-care devices are rapidly becoming smaller, user friendly, and can monitor, detect, and analyze vital physiological parameters such as heart rate, blood oxygenation (SpO_2), temperature, and respiration. Telemonitoring has proven to be one of the most efficient ways for continuous and remote tracking of the health status of patients.[12,15] It represents virtual extension of the hospital space and reduction of crowding at health care facilities. NP health monitoring devices (PHMD) are replacing conventional standby hospital monitoring systems because of their portability, mobility, affordability, and accessibility. This fit is being achieved as a result of major revolutions in computer informatics, smart phones, energy-efficient, miniaturized electronics, and sensors which can provide health information to the patient directly, to the physician via the internet, and to researchers as aggregated databases.[15] NP to a WHO report of 2017, cardiovascular diseases (CVD) are the leading causes of death globally which represents 32 percent. Over three quarters of CVD deaths accounting for 75 percent takes place in low- and middle-income countries.[16–19] CVD are a group of disorders of the heart and blood vessels which are caused by a blockage that prevents blood from flowing to the heart or brain. Furthermore, once a patient starts losing oxygen, a doctor has less than three minutes to prevent risk of brain damage, heart failure and death. Oxygen saturation level of a healthy person should never fall below 95%, and oximeters can detect small changes in oxygen level as little as 1%.

The oxygen level of a patient can be used to predict and detect chronic obstructive pulmonary diseases (COPD). COPD can lead to hypoxia, a condition marked by low oxygen levels. Hence, CVD are arguably the most comorbidities in chronic obstructive pulmonary disease (COPD), and their presence is associated with increased risk for hospitalization and CVD-related mortality.[16–19] People suffering from chronic diseases usually need constant monitoring of their vital signals. These biomedical signals provide information about the patient health status, allow for better diagnosis and treatment. Unfortunately, in conventional healthcare systems, electrocardiogram (ECG) and SpO_2 are monitored in fixed places like hospitals, so the patient has to come to the hospital to diagnose some heart disease.[20] Electrocardiogram (ECG) represents the electrical activity of the heart, and it reveals the health status of the heart.[20] NP medical development and the adoption of telemonitoring, monitoring of patient's physiological information is made easy which leads to reduction in the current burden on public health system and promote routine health self-check by mobile healthcare user. Hence, the development of portable, cost-efficient system with a reliable database that is easily accessible with Mobile phones has become most essential in telemonitoring. In recent years, several works have attempted to approach the challenge of real time monitoring, designing monitoring systems based on microcontrollers and small screens. Interfacing of Biomedical Diagnostic Devices with Internet of Things (IoT) is an example of such works.[12] NP a multi-parameter portable healthcare device monitor based on android smart phone, Bluetooth Low Energy and a microcontroller unit is presented. It is a low-cost multi-parameter monitoring system based on a low-power ATmega328 microcontroller, with data acquisition units comprising the AD8232 and the MAX30100 sensors. The controller converts the analog signal into a digital signal via an inbuilt analog to digital converter which conditions and filters it. The signal is then transmitted via a Bluetooth module. The real time data is received by a companion android base application that provides data communication via a distributed protocol and displayed in real-time.

Methodology

The aim of the portable healthcare monitoring device is to continuously monitor and measure the patient vital signs to detect and prevent a heart attack before it occurs. Figure 1 shows the block diagram of the device. The sensors convert the detected physiological parameters into electrical signals which will be processed using the digital signal processor (DSP) according to an algorithm. Then, the processed data will be transferred to the android application interfaces via serial port Bluetooth communication. The android studio further processes the received data, plots the NP (ECG) graph, and displays the SpO_2 using algorithms written in java programming language. The Android application also offers communication between the patient and the doctor. The measured data is recorded and uploaded to a database from within the patient's accounts. An Electrocardiogram (ECG) is a graphical presentation of the heart activity over time. It is recorded by placing electrodes on the human body at certain points, and then measuring the potential difference between the electrodes caused by the depolarisations and repolarisations of the heart. The graphical presentation of the ECG can be interpreted, so that normal and abnormal rhythms of the heart can be detected and diagnosed.[20] Pulse oximetry is the non-invasive measurement of the oxygen saturation which is the percentage of SpO_2 concentration. It is used for a rapid assessment of a patient's respiratory function to determine the onset of hypoxemia (oxygen starvation) or COPD (Chronic obstructive pulmonary disease).[21,22]

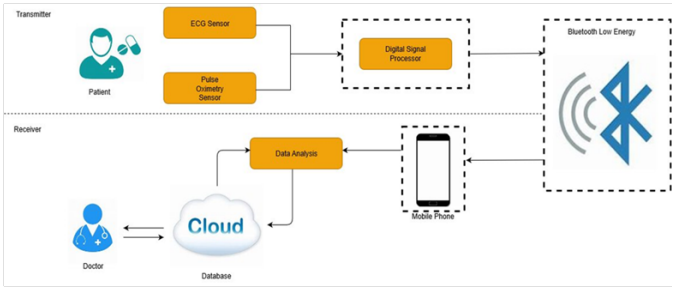

Figure 1 Block diagram of the PHMD system design.

Oxygen is one of the most important elements for a living human being. Hemoglobin in the blood carries oxygen from lungs to the rest of the body where it releases the oxygen to burn nutrients to provide energy to power the functions of the organism and collects the resultant carbon dioxide to bring it back to the respiratory organs to be dispensed from the organism. Optimal hemoglobin in O_2 is defined by the SpO_2 values of 95 percent and above.

The modern basis for determining SpO_2 concentration uses light sources and photosensors.[21,22] Modern hospital bedside equipment includes a SpO_2 module based on the same fundamentals. However, these hospital-based devices are expensive, bulky, and in their current form, their usage is limited to hospitals, health clinics, and some doctor's offices. To enable individuals interested in tracking their body's key health indicators, a solution that is both portable enough to wear in comfort and affordable for patients is needed.

Hardware unit

The hardware unit of this project is an integration of three major parts: the data acquisition unit, signal processing unit, and the communication unit.

Data acquisition unit: This unit is mainly responsible for obtaining patient's physiological parameters utilizing sensors. Sensors are devices that detect or measure the variations (in this case vital signs) and send them as electrical signals. The two sensors used in this work are the AD8232 and the pulse oximeter. The Analog Device AD8232 is a single-lead, heart rate monitor integrated circuit for pulse detection application. It is an integrated signal conditioning block for ECG and other biopotential measurement applications which are designed to extract, amplify, and filter small biopotential signals in the presence of noisy conditions, such as those created by motion or remote electrode placement. NP the vitals as analog signals to the analog to digital converter (ADC) in the Digital Signal Processor (DSP) where it can then be further processed. The basic processing algorithm involved setting threshold values to detect heartbeat peak values and calculating pulse rate in beats per minute (BPM). If the BPM is too high or too low, a flag is sent to the Android App to alert the patient and the doctor. Another sensor, the MAX30100, is an integrated pulse oximetry and heart rate monitor sensor that combines two LEDs, a photodetector, optimized optics, and low-noise analog signal processing to detect pulse oximetry and heart-rate signals. In this application, it is used as pulse oximeter to measure the oxygen saturation in the hemoglobin. It is operated at 1.8V-5.5V power supplies and can be powered down through software with negligible standby current which as a result allows the power supply to remain connected at all times.

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Digital signal processor (DSP)

The digital signal processor (DSP) is a microcontroller based on the ATMEGA328 microprocessor. The DSP filters, calculates, and prepares the measurements for transmission. The ATmega328 is an 8-bit AVR RISC-based microcontroller that combines 32KB ISP flash memory with read-while-write capabilities, 1KB EEPROM, 2KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8 – 5.5V. Figure 2 & Figure 3 show the interfacing of the DSP with the AD8232 module and the MAX30100 module respectively.

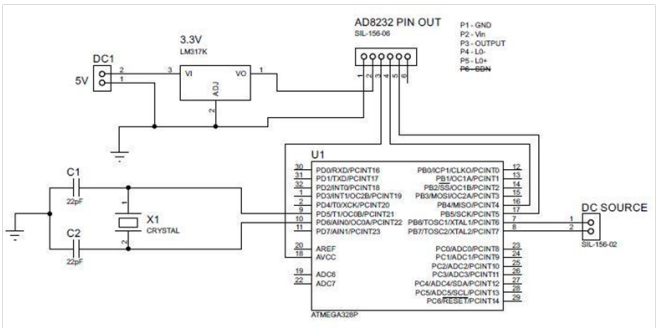

Figure 2 Interfacing AD8232 with DSP.

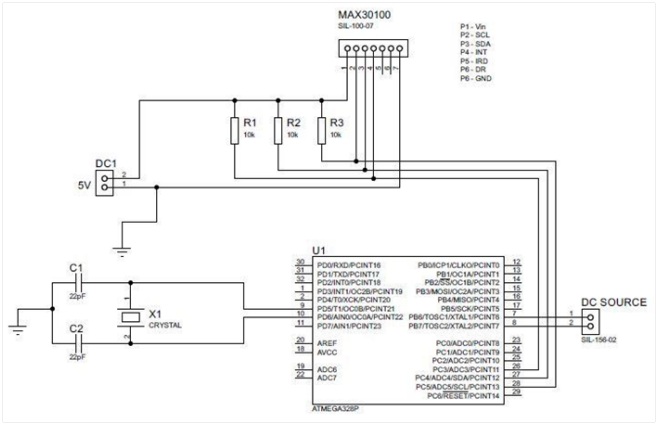

Figure 3 Interfacing the MAX30100 with the DSP Unit.

Communication unit

The Bluetooth HC-05 serial port module of Figure 4 is responsible for the communication by sending data from the DSP to the android application interface. Bluetooth Module HC-05 is a class 2 Bluetooth Low Energy (BLE) module with a Serial Port profile which can be configured either as a Master or as a Slave. The Bluetooth module is small and is very simple to use. It has 6 pins; KEY, RXD, RXD, 5V, 3.3V, GND out of which only the RXD, TXD, 5V, and the GND pin were used. The 5V and the GND pins of the Bluetooth module were connected to the 5V and GND pins of the DSP. The pins 30 and 31 of the DSP were initialized as the Bluetooth Transmitter and Receiver respectively as shown in Figure 4. These connections enable Bluetooth communication between the DSP and the android device.

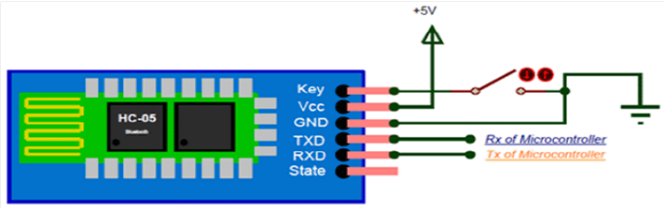

Figure 4 Interfacing the bluetooth module with the DSP unit.

Software unit

Several software tools were used in order to program the Arduino board. The software controls and directs the operations of the hardware unit.

Coding in C-language

The microcontroller programs which performed three critical functions were written in C-language. These functions are the calculation of the beat per minute (BPM), blood oxygen level (SpO_2), sending of the measured data, and initiating the alert system when an abnormality is detected.

Android studio

An Integrated Development Environment (IDE) is an environment for applications development that will run on Android OS. It's an alternative for the Eclipse Android Development Tools widely used in the early 2000s. Android studio was used to develop android application that is compatible with the components. The developed application performs the following activities:

Registration: The first activity enables new users to register with the basic details such as email and password for authentication, verification, and security against third parties as shown in Figure 5. The authentication and verification of email are done using the firebase technology by google.

Authentication: Registered users can access their physiological information upon authentication of their emails and password remotely as illustrated in Figure 6. A user is required to input their profile details as shown in Figure 7. This is to enable the mobile application to provide customized solutions for users.

Interfacing: The mobile application contacts the sensors through the HC-05 Bluetooth Module which is the most ideal protocol of sensors-smart phone systems. When the hardware is turned ON, the HC-05 starts waiting for connection with a mobile application. On establishing connection, the App is now ready to send and receive data from the hardware.

Data format and data rate

The maximum data transmission rate for BLE is 2Mbps. However, transmitting data at this rate leads to loss of packets resulting in the distortion of the displayed ECG signal. Data is transmitted at a rate less than 1Mbps is employed as the transmission rate. The PHMD hardware transmits the signals to the mobile App every 20ms with each packet containing 20 bytes of data for the ECG and 16 bytes of data for SpO2.

Data parsing and display

The Class Message in the Java Library was used. According to the android BLE API, every time the mobile App receives a new ECG

packet transmitted via BLE, the callback function on message in class Bluetooth Receive Thread is used. After passing the data, an array of strings is obtained which contains the ECG points values used to plot the ECG graph. This array of strings is sent to the generateData() function where it is converted to integers for plotting the ECG graph. For the SpO_2, the App wait until it gets a value whose magnitude is greater than 80, to avoid false values because of noise signals from the hardware. Once a valid value is obtained, the function terminates, and the value is stored.

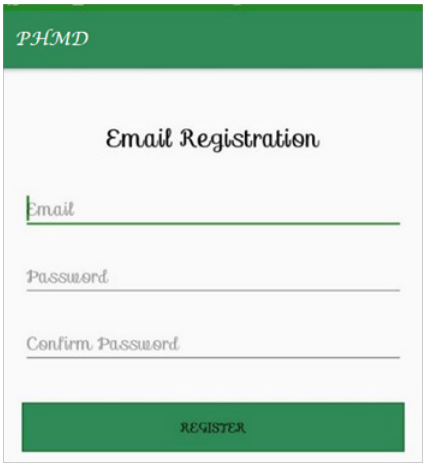

Figure 5 Registration of new users.

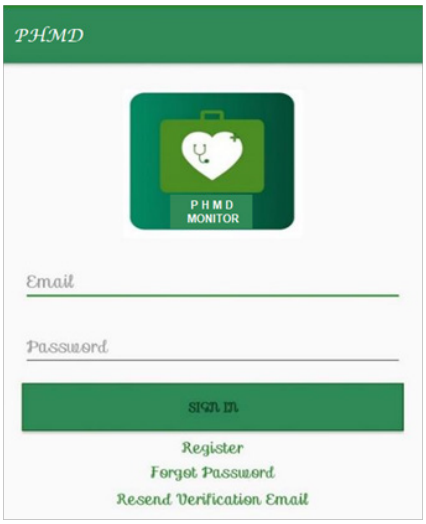

Figure 6 Sign-in of user.

History management

Each time a test is taken, the data is stored locally by clicking the save button. Structured Query Language (SQL) as saving data to a database. The SQLite is a lite SQL database on android phone. For android developers, Google has offered an API to access the SQLite The data stored is secured and is only accessible by the user upon authentication. The data is saved on the phone in a folder that is associated with the App and is eventually pushed to a cloud-based database.

Display interface

A chart engine is used to display the ECG signal on android phone. There are many chart engines for android. The GraphView and the LineGraphSeries are the major classes used in this work.

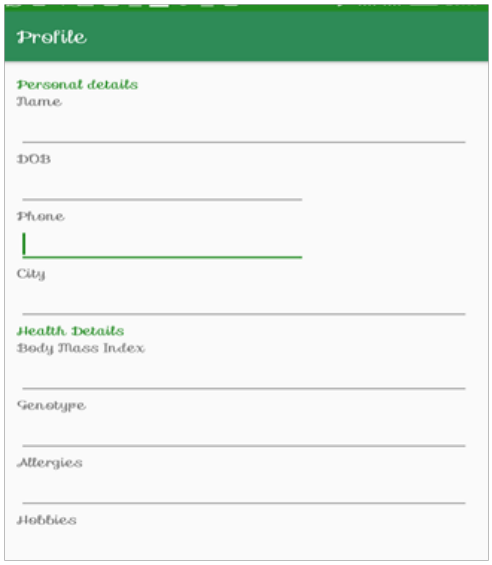

Figure 7 New user's profile.

Tests and results

The Portable Healthcare Monitoring Device (PHMD) was subjected to tests. The ECG waveform, heart rate and oxygen level values were acquired, processed by the digital signal processing unit, and transferred to the android application by the Bluetooth. At the receiving end, the body vital signs were displayed on the mobile application. The waveform of the bio signal and measured vital signs are shown in Figure 8 for a subject as displayed on the android application.

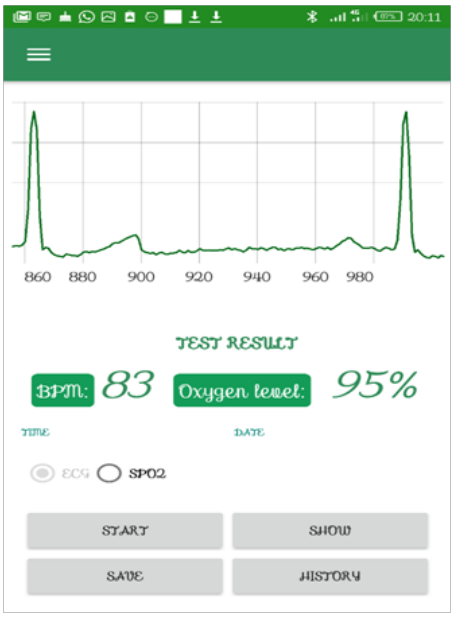

Figure 8 ECG graph and measured vital signs of a subject as displayed on the android application.

Conclusion

A Personal health monitoring device (PHMD) for ECG display, SpO_2 and pulse rate (beat per minute) measurements has been developed. The Device is affordable, portable, mobile and consumes

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less power. The device is ready for clinical trial. The mass production of this device will reduce overcrowding of patients at the healthcare centers as monitoring which is part of patient healthcare services can be done remotely and effectively. Access to healthcare is improved. Hospital space becomes wider virtually and population of patient is reduced.

Acknowledgements

None.

Conflicts of interest

The authors declare that there is no conflict of interest.

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