Design of Mobile Healthcare Monitoring System Using IoT Technology and Cloud Computing

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Abstract. This project presents an implementation of wearable, portable, low power consumption, real-time remote bio-signals monitoring system based on the internet of things technology. This implementation provides an improved step-in remote health monitoring field. Numbers of people, who require health care increase year by year and the conventional bio-signals monitoring systems require patients’ attendance in person inside hospitals. This might cause an inefficient situation to take care of the patients, especially those who have critical and unstable health conditions. Therefore, internet technology along with modern electronic devices could offer promising solutions in this field. Based on that, this project utilizes a mobile application as an IoT platform to monitor remotely the live ECG signal, heart rate, SPO2, and the body temperature of patients. The signals are measured and processed by using a microcontroller-based device (Arduino). The main contribution of this paper is sending an electrocardiogram (ECG signal) to a specific smart mobile phone to be watched by a doctor. This assists in heart diseases diagnosing before the worst case can happen. Finally, the obtained results of this project are illustrated on both smartphone and personal computer (PC) as well.

1. Introduction

IoT technology makes certain physical events can have an impact on other things remotely. Using this technology can execute controlling or monitoring something somewhere in the world. Additionally, this technology provides a communication channel between human-to-human, human-to-smart devices, and smart devices-to-smart devices without human interaction. IoT applications have been increasing by the time such as smart wearable devices, smart cities, home automation, remote control, and monitor systems. Also, IoT technology has a modern evolution in healthcare systems and fitness applications. This can be an essential step to change the conventional healthcare systems which require patients’ existence inside hospitals or clinic centers to check their health parameters. On the other hand, there are some challenges of this technology such as data management, security, privacy, human-cloud interface [1].

IoT technology utilizes diverse types of communication protocols for example (IPv6) Wi-Fi, (IPv4) Wi-Fi, 6LoWPAN, ZigBee, (BLE) Bluetooth Low Energy, Z-Wave, (NFC) Near Field Communication, SigFox, 2G-3G-4G Cellular, Thread, and LoRaWAN. Each protocol has distinguished properties that allow IoT project designers to use any protocol to meet their requirements and limits [2, 3]. In this paper, we used Wi-Fi protocol IEEE 802.11, standard IPv4 address, beside a 3G cellular network to send data.
from sensors to mobile application “Blynk”. Moreover, NodeMCU and Arduino UNO microcontrollers are applied. Arduino microcontroller family has been used in many fields and it is considered in many experimental models and prototypes [4, 5]. Furthermore, the IoT platform is Blynk mobile application. It receives, stores, visualizes data, and provides hardware control remotely. To use Blynk four steps must be accomplished such as downloading the mobile app from Apple Store or Google Play, installing its libraries on the developer PC, creating widgets inside the app, building the desired hardware design and writing code. There are a lot of examples in “examples.blynk.cc” to make users familiar with Blynk code standards. Moreover, this IoT platform includes, besides the Blynk application, the Blynk server which provides a communication channel between the IoT project’s hardware and the cloud. This server can be built on a Blynk cloud or a local server in case the IoT system is used in a limited area. Finally, Blynk libraries are responsible to communicate between the server and the processing instructions. The impactful thing in Blynk that it is installed in a caregiver smartphone so, the interface layout is constructed on that phone only. This means that no one can see the data except the caregiver. This keeps the data private and secure. Finally, this application delivers an opportunity to monitor more than one patient at the same time by creating a new page for each patient.

In this paper, four health parameters monitored in real-time continuous such as body temperature, ECG signal, heart rate, SPO2. These health parameters are monitored in the CCU (Coronary Care Unit) rooms in hospitals. This project is effective equipment for patients who are recovering from a heart attack or patients who suffer from chronic cardiovascular system issues. It follows up their case whenever and wherever they are in the world. Some chronic diseases such as the cardiovascular system and diabetic require continuous monitoring to prevent the situation get worse [8]. Firstly, the body temperature is one of the vital signals that should be monitored for patients because it informs about patient’s metabolism situation, some medicines side-effects, and balance rate between heat generation and heat loss. Secondly, the ECG signal is important to be monitored to prevent cardiac arrhythmia cases such as Bradycardia, SVT (supraventricular tachycardia), AF (Arterial Fibrillation), VT (ventricular tachycardia), and VF (Ventricular Fibrillation) which are life-threatening conditions [18][6]. While the heart rate monitoring can diagnose some cardiac diseases before it happens and making sure the case is stable [7]. Finally, the SPO2 (Saturation of Peripheral Oxygen) parameter indicates the ratio of oxygenated hemoglobin amount to the whole hemoglobin amount. The oxygen is a vital element to make body cells work and perform their functions.

This paper is structured as follows. Section 2 shows a literature review of this IoT application. Next, Section 3 explains the design and implementation of this project. After that, Section 4 discusses the results and it performs comparisons between this project’s sensors and trusted medical devices. Finally, Section 5 introduces the conclusion of this work and it gives brief suggestions for future work in this field.

2. Related work
Acute health conditions might lead to sudden death. Many people die suddenly around the world because of dysfunction in one or more body organs. Before that happen, these organs produce abnormal signs. These signs, which called bio-signals, can be detected and collected via sensors.

Based on the search scope, the remote healthcare systems based on IoT technology depends on microcontroller and gateway to upload data. Arduino microcontroller family is used frequently in this field. Some projects utilize NodeMCU which is ESP8266 based board [9]. While others utilize Arduino UNO with ESP9266 module [12]. Other projects make matching between one of Arduino boards and Raspberry Pi board. The processing is performed by the Arduino board and the Raspberry Pi is the gateway [13]. Moreover, projects depend on Raspberry Pi for processing and uploading data to the IoT server [15]. However, some projects depend on the Arduino board for processing purposes and utilize the smartphones as gateway [16].

Sensors connected to the microcontroller via wires like most of the projects [9-15] or via a wireless protocol such as the HC-06 Bluetooth module [16].
There are various types of IoT platforms. Some of them are created via developers from scratch using web design skills such as Node.js server and WebSocket library also, HTTP server and the developed web-based GUI interface [9,11,14]. On the other hand, Android Studio provides a good opportunity for mobile application developers to build up their own healthcare applications, so, some projects depend on that approach [10,13]. For example, one mobile application is called “Abuelómetro” and another one is called “3rd Nurse”. Additionally, there are some mobile applications are created for IoT projects in general. As a result, these types of applications can be utilized for healthcare systems such as Blynk mobile application [16].

Data storage can be achieved by two methods. One is by storing data in an online (cloud-based) database such as MySQL and Google Firebase Database [11,13]. However, the other projects depend on the mobile applications server. This approach is considered less complex than the first approach. For example, Blynk and Abuelómetro applications save health data on their server [16,10].

The monitored health parameters are almost heart rate and body temperature. The heart rate is monitored by using two types of sensors one of them is analog [9,11,12,16] and the other one is digital which usually can monitor the SPO2 as well [10,15]. Secondly, the body temperature is measured by using two types of sensors LM35 [9,11,12] and thermistor NTC [16]. Furthermore, there are other parameters such as Galvanic Skin Response (GSR) to detect skin conductivity [13]. This detects skin conductivity which increases when human is affected emotionally. Also, some projects detect patient location within an indoor limited area by using the “iBeacon module” instead of the GPS which is less accurate in the indoor locations [15]. Other projects monitor patients’ safety from falling hard on the ground by using the fall detector sensor ADXL335 (3-Axis Accelerometer) [15]. Finally, one project utilizes the AD8232 ECG sensor [14]. This paper did not mention the medical benefits of the real-time monitoring of ECG. Also, it utilizes a web page to present only the ECG signal without any elegant layout. There is no possibility to monitor more than one ECG signal. Also, the ECG signal quality was not efficient. This problem stemmed from the fact that the output signal did not include all the ECG signal parameters such as P-Q-R-S-T and some of them disappear. Finally, this paper did not verify the signal practically and accurately. Based on that, the achieved signal in this project cannot be trusted and used for diagnosing purposes.

Finally, security and privacy approaches in this review can be divided into three methods. First, some healthcare project requires login information (username and password) to access patients’ health data [10,13]. In contrast, some projects depend on creating their interface on a specific device to make sure the accessibility is restricted by that device users. This can be done in some mobile applications [16].

3. Design and implementations
In figure 1 the complete circuit of sensors, devices, and their connection are illustrated.
3.1. Sensors

3.1.1. Heart rate sensor

Heart pulse rate sensor that is utilized in this project (MAX30102) is a non-invasive optical device (figure 2) used for achieving two main functions, detecting the heartbeats and peripheral capillary oxygen saturation (Spo2). There are two non-invasive methods for calculating the heart rate and Spo2 values, transmitted mode and reflected mode (figure 3). The sensor is used in this project uses reflected mode.

Figure 1. The complete circuit of the live health monitoring project

Figure 2. Max30102 sensor

Figure 3. Non-invasive reflected light measuring
For measuring the reflected light, this sensor utilizes two types of lights, red and infrared. The red light has a wavelength of 650 nm and the infrared light has a wavelength of 950 nm. Oxygen-saturated hemoglobin (oxygenated blood) and non-oxygen-saturated hemoglobin (deoxygenated blood) absorb different amounts of each light. So, the reflected light will be received by the sensor and through an algorithm, the final value for the Spo2 will be deducted.

For calculating the heart beats per minute another approach is used. The blood needs high pressure to be pumped out of the heart to other body members. It occurs with the heartbeat and it causes the arteries to feel an amount of strain (blood pressure) when the blood flows in them. Arteries are responsible for carrying the blood out of the heart. So, the blood pressure leads to swelling and contracting of arteries, therefore the volume of the artery in the body parts (fingertip in this project) increases and reduces. When the volume increases, there will be more hemoglobin in the section area and consequently, the amount of infrared light will rise and the reflected signal back to the heart rate sensor will be reduced. These variations in the reflected light will result in a fluctuated signal called photoplethysmogram (PPG).

It is important to note that there are also tissues, bones and venous blood surrounding the arteries and some amount of the applied light from the sensor is also absorbed by them. Nonetheless, these members
do not produce an alternated reflective light and they just are DC elements of the signal (direct signal without fluctuations) and can be easily bypassed by the sensor circuit or in the signal processing stage (figure 6).

Figure 7 shows a flowchart describing the process of calculating the heart rate beats per minute. For achieving this task, the PPG wave is filtered by a low pass filter, so we can obtain noise reduced waves to measure the heart pulse rate. Then the maximum and minimum peaks of these waves are detected. By checking their peaks, the validity of an actual heart pulse is determined. In order to measure the interval between pulses, at least two consecutive heart pulses must be correctly detected. Then the last twelve intervals will be stored in an array and the median of these intervals is calculated. In this project instead of calculating the average, the median calculation is used, because the median function will result in more accurate final value if there are some anomalies in the results. Then the median value is converted to the heartbeats per minute (BPM) and along with the Spo2 value are sent to the Blynk cloud server.

![Figure 7. Flowchart of the heart pulse and Spo2 sensor](image-url)
3.1.2. ECG Sensor

The electrocardiogram (ECG signal) represents the electrical potential of the human heart. This signal is started from a specific spot which is called “S-A node (sinoatrial node)” which is located on the upper left side of the atrium. Then, the signal reaches to “A-V node (atrioventricular node)” which is located in the middle of the heart approximately. Next, the electricity goes “bundle of His”. The ECG signal consists of P: atrial depolarization, QRS complex: ventricular depolarization and atrial repolarization, and T: ventricular repolarization [18]. See figure 8.

Figure 8. The standard ECG signal which shows the intervals

The ECG amplitude is in the microvolts range and its frequency within 0.01 HZ to 100 HZ range. Therefore, to display it, a bandpass filter and an amplifier should be applied to the signal. The bandpass filter range is 0.5 HZ – 40 HZ [16]. The most important things to diagnose via ECG signal are the intervals between the pulses, the shape of each pulse. The normal intervals are: R-R interval (0.6 - 1.2) seconds, P-R interval (0.12 – 0.2) seconds, QRS complex (0.08 - 0.12) seconds, Q-T interval (0.35 – 0.45) seconds [17].

The ECG sensor is used in this paper is “Single-Lead ECG sensor AD8232” (figure 9) which is an analog sensor with 3.3V operating volt manufactured by Sparkfun company. It includes three electrodes (RA, LA, and RL) which can be placed under clothes confidentially (figure 10) RA (Right Arm), LA (Left Arm), and RL (Right Leg). This sensor includes two analog filters, the first one is a high pass filter with a cut off frequency of 0.48Hz and the second one is a low pass filter with a cutoff frequency of 40Hz to achieve the required bandpass filter. Sensors’ pins are 3.3V, GND, Output, LO-, LO+, and SDN. The output pin gives the ECG signal. LO- and LO+ pins are connected to the microcontroller to inform it if one of the three electrodes loses its connection to the patient’s chest and they send a HIGH signal to the microcontroller if the disconnection occurs. Therefore, the microcontroller can send a warning message automatically based on that. Finally, the SDN pin is used to shut down the sensor to save battery. It is an active low pin and the microcontroller can shut down the sensor automatically. The main issue with this sensor which is very sensitive to motion. So, it requires a rest position to read perfectly. See figure 11.

Figure 9. AD8232 single-lead ECG sensor  Figure 10. ECG electrodes suitable positions
The ECG code partition is executed firstly by checking the electrodes attachment case. Then, the microcontroller reads the analog input signal and performs a smoothing process on the signal. After that, the samples buffered in an array before sending them periodically to the Blynk cloud server. The processing approach is illustrated in figure 12.

![ECG sensor connection to NodeMCU](image)

**Figure 11. ECG sensor connection to NodeMCU**

**Figure 12. Flowchart of the ECG sensor**

3.1.3. Body Temperature Sensor

Maintaining the body temperature is essential to have a healthy condition, because catalyzing the chemical reactions is the responsibility of enzymes in body cells and these enzymes must have the appropriate temperature to be capable to do this task. High body temperature can result in heat stroke, dehydration, and death if it is not treated. Also, low body temperature can lead to hypothermia and death if it is not dealt with.

Therefore, obtaining instantaneous information about body temperature helps to avoid the mentioned problems. In this paper, an LM35 analog temperature sensor (figure 13) is used to measure body temperature. This sensor is able to read temperatures from $-55^\circ$ to $+150^\circ$C and has a $0.5^\circ$C tolerance. This sensor is put under the body arm (axilla) and is connected to the analog input of the Arduino UNO as it is shown in figure 1 and figure 14. The process of acquiring the Celsius temperature is illustrated in figure 15. The Arduino imports the analog data from the sensor to its analog pin and it converts the data to a digital value using an internal analog to digital (A/D). Then the digital value is converted to a Celsius temperature. Afterward, this temperature is transmitted to the NodeMCU to be sent to the Blynk Cloud Server using an ESP8266 WI-FI chip included in the NodeMCU module.

![Figure 13. LM35 sensor (body temperature)](image1)

![Figure 14. LM35 sensor connected to the Arduino UNO and NodeMCU](image2)
3.2. Communication between Arduino UNO and NodeMCU

3.2.1. Why two microcontrollers are used?
For sending the data to the Blynk cloud server, a chip with Wi-Fi technology is required. Therefore, in this paper, a NodeMCU module is chosen for satisfying this purpose. Nonetheless, some problems cannot be solved by using this chip alone. The first challenge is that the NodeMCU has only one analog input and in this project more than just one is required. The second issue is some libraries are just dedicated to just some specified microcontrollers not all of them. Thus, Arduino UNO is selected to connect to the NodeMCU to establish a communication of data between them and to approach the challenges which are mentioned.

3.2.2. Method of communication
Figure 16 illustrates a flowchart describing the established communication between NodeMCU and UNO. For ensuring that the NodeMCU serial communication is properly connected to the Arduino UNO, a very short message from the former device is sent to the latter one. Afterward, the Arduino verifies the incoming message and prepares the JSON document to be sent to the NodeMCU. JSON is a structured text-based format used for the exchange of data. Its structured design helps to be certain that the received data is in the appropriate format without losing or overlapping between data. In this paper, the values of heart BPM, Spo2 and the body temperature sensor are sent to the NodeMCU using the Json document while the ECG sensor is directly connected to the NodeMCU. After receiving data by this device, there is a function that ensures that all the data have been received, after that the received information is checked to confirm that data is an appropriate format. Consequently, the received data is sent to the Blynk cloud server.
3.3. Blynk

For illustrating the patient’s information an IOT platform called Blynk is used. Blynk cloud service enables live monitoring of the patient’s condition in an elegant and professional environment. It also has the ability to be run on a local server for example inside or nearby a hospital and the cloud service secures a live stream of information about the patient’s condition outside the hospital.

3.3.1. Blynk app design layout

As is shown in Figure 17, at the top of the page a live graph for illustrating a live ECG signal is inserted, while below it there are three gauges for live visualization each of heart rate in BPM, Spo2 in percentage and the Celsius body temperature.

Figure 17. Design layout of live health monitoring app
4. Results and discussions

4.1. Heart pulse rate sensor

For the purpose of this project, four persons have been tested. The first person is a young male healthy person, the second one is a young female person, the third person is a senior male and the fourth one is a senior female. The heart rate for each of these persons. To compare the accuracy of the heart pulse rate sensor in this project, it is compared with three other methods as it is illustrated in table 1. The first method is to put the index and middle finger on the underside of the opposite wrist under the base of the thumb and check the beats for example in 15 seconds and multiply the beats by 4 so the heart BPM can be calculated. This method is manual measurement. The second method is to use a pulse oximeter fingertip device (figure 18) and record the shown heart rate. The third one is to use a digital blood pressure device with heart rate measurement (figure 19).

| Table 1. Comparison between this paper heart rate sensor and three other methods |
|-------------------------------------------------|-----------------|-----------------|----------------- |
| This Paper (BPM) | Manual (BPM) | Pulse Oximeter Fingertip (BPM) | Digital Blood Pressure (BPM) |
| Person No.1 | 77 | 76 | 76 | 77 |
| Person No.2 | 82 | 81 | 82 | 81 |
| Person No.3 | 67 | 69 | 68 | 68 |
| Person No.4 | 71 | 70 | 69 | 70 |

![Figure 18. Pulse oximeter fingertip device](image)

![Figure 19. Digital blood pressure](image)

4.2. Spo2 sensor

Although the Spo2 sensor is integrated with the heart rate sensor, it is compared with just an available commercial pulse oximeter fingertip device, which is a very common tool in hospitals to measure patient’s Spo2 (figure 18).

| Table 2. Comparison of Spo2 sensor with a pulse oximeter fingertip device |
|-------------------------------------------------|-----------------|----------------- |
| This paper Spo2 sensor | Pulse oximeter fingertip Spo2 value |
| Person No.1 | 97% | 97% |
| Person No.2 | 98% | 97% |
| Person No.3 | 95% | 96% |
| Person No.4 | 96% | 96% |
4.3. Body Temperature Sensor (LM35)
Both the body temperature sensor (LM35) and the digital thermometer (figure 20) are put under the body’s arm and their measurements are compared (table 3).

|                | This paper body temperature (ºC) | Digital Thermometer (ºC) |
|----------------|----------------------------------|--------------------------|
| Person No.1    | 36.1                             | 36.5                     |
| Person No.2    | 37.11                            | 36.4                     |
| Person No.3    | 36.44                            | 36.7                     |
| Person No.4    | 37.22                            | 37.1                     |

![Digital thermometer device](image)

**Table 3.** Comparison of body temperature sensor versus a digital thermometer

The obtained results from all sensors demonstrate that there is a negligible difference in measurements and their performances are compatible with their counter commercial and medical devices.

4.4. ECG sensor
The ECG signal is collected from a healthy, young male at a rest situation to achieve a periodic and clear signal. The main factors in the ECG signal are the shapes and the intervals of the heart pulses. We achieved this signal on the serial plotter of the NodeMCU microcontroller (figure 21). When we compare this signal with the standard ECG signal figure 8, we can point the ECG signal parameters such as P-Q-R-S-T.

![ECG signal achieved on Serial plotter of the microcontroller](image)

**Figure 20.** Digital thermometer device

**Figure 21.** ECG signal achieved on Serial plotter of the microcontroller

By this, we achieved the first goal which is all the ECG signal parameters appear and all of them are shaped well. Now we need to prove that this signal is periodical. Therefore, we extracted the ECG signal from the microcontroller serial monitor using PuTTy software which is an open-source serial terminal...
emulator. Then, we took the data to Microsoft Excel sheet to export the data and visualize it on MATLAB software (figure 22). MATLAB assists us to verify and check the intervals between the pulses of the examined ECG signal.

**Figure 22.** The ECG signal on MATLAB

The verification process focuses on the intervals of the ECG signal. First, we verify the R-R intervals and peaks values. See figure 23. From the figure, we can state that it is a periodic wave, and it has the same peaks value. Second, we verify the P-R intervals and peaks values. See figure 23. Also, it is periodic, and it has equal peaks values.

**Figure 23.** ECG on MATLAB to verify (R-R) and (P-R)

Finally, we examined the width of the QRS complex in the achieved signal. See figure 24. From the figure, we can claim that the width of the QRS complex is constant.
Based on this analysis, we can support this sensor to be used as a trusted ECG signal sensor and it can be used in healthcare systems. This can help doctors to diagnose heart diseases efficiently. The uploaded ECG signal to the Blynk application is shown in figure 25.

4.5. Blynk
The final patient’s condition is uploaded on the Blynk cloud server as live stream of the data as it is shown in figure 26.
5. Conclusion
To sum up, this paper presents an experimental model to achieve wearable, portable, low power consumption, real-time remote bio-signals monitoring system based on the internet of thing technology. This implementation achieves trusted and verified bio-signals. The verification is done by performing comparisons between this project’s readings and the medical devices which are used by doctors and health providers. Also, those bio-signals are uploaded successfully to Blynk mobile application. This makes health professionals capable to monitor and diagnose more than one health parameter at the same time. Also, This mobile application provides an opportunity to supervise more than one case at the same time. Finally, this project is affordable to be purchased.

5.1. Future work
There are other health parameters that can be monitored such as cuffless blood pressure, non-invasive blood glucose, respiratory rate. Additionally, machine learning technology can be considered as a vital addition to the healthcare monitoring system because it will assist doctors to diagnose diseases faster and more accurately than the conventional diagnosing approaches. Furthermore, in case of urgent, when there is an abnormal signal produced from the patient’s body, there are some approaches can be added to this project to handle this need. First, mobile calling and SMS messages sending to doctors, patients, relatives, and ambulance centers can be performed by adding SIM800L GSM Module to this project. Emails also can be sent via NodeMCU automatically to specific people's email accounts to save lives. Second, a wearable DC defibrillator can be attached to the patient body to apply DC shocks automatically when sudden VF (Ventricular Fibrillation) is happening. Finally, this system can be equipped with an automatic ventilation system to provide the oxygen automatically in case the SPO2 % reduced less than 90%.
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