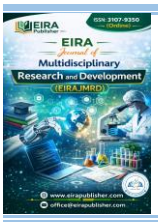

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Design and Software Implementation Real-time Database of Health Monitoring System

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Abstract **Original Research Article**

The study embarked on design and software implementation real-time database of health monitoring system The number of sudden death cases is on the rise, especially in developing countries. With inadequate and inconsistent health monitoring techniques and technology, the issue of sudden deaths has become of great concern. In this study, the issue on inconsistent patient health monitoring was expatiated upon. To address the above-mentioned issue, an IoT based patient health monitoring system was proposed to aid medical practitioners to monitor their patients beyond the four walls of their medical firms. The proposed solution was a device capable of attaining health data from its users and transmitting the data to an online database where they can be accessed, through a website, from any location. By incorporating a heart rate and pulse oximetry sensor, a body temperature sensor, an environmental temperature and humidity sensor, and a Wi-Fi-enabled microcontroller unit, health data was able to be sensed and transferred to a database over the internet where they could easily be retrieved. Various tests of the proposed system's health sensors were performed and compared with results from standard medical equipment, showing minimal variations between the two sets of results and thus giving the system viability. Patient health monitoring plays a crucial role in medical procedures and through the implementation of this system, monitoring can be made more frequent for patients with less demanding underling health conditions.

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Introduction

Many innovative medical inventions have been made over the past centuries which have utilized the advancements in science and engineering to perform medical operations more efficiently and precise than ever before with popular examples being the electrocardiograph machine and the magnetic imaging resonance (MRI) scanner. Also, there have been a multitude of scientific breakthroughs in medicine such as the development of vaccines in the 18th century and the discovery of penicillin in 1829 [2] [3].

Health institutions depend on various forms of technology to properly administer and monitor patients in their firms, thus the medicine and health sector indisputably benefits from technological advancements. One of the more modern advances in technology is the internet of things (IoT) which is a system of interrelated computing devices, capable of transferring data over networks without the need for human

intervention. Such devices or 'things' usually contain sensors that collect data and transmit the data to an IoT gateway which then transmits the collected data over a network such as the internet. The Internet of Things is a rapidly expanding technological trend that enables devices or gadgets that are connected through a network (such as the internet) to gain the ability to acquire, process, and share information. The internet of things is known as a technology that has demonstrated its existence as a network of machines or gadgets that can communicate with one another [4].

The history of the internet of things can be traced back to the introduction of the internet in 1989. The internet is a world-wide system of interconnected computer networks, allowing for computers to communicate on a global scale. The first Internet device that could be activated and disabled with the Internet was designed by John Rom Key. Then, in 1999, a British technology pioneer named Kevin Ashton introduced a system in which physical objects could be linked to the Internet via sensors, a system now referred to as the internet of things. [5].

With the recent boom of interest in IoT technology, a variety of devices are now available to consumers, businesses, and individuals alike, ranging from small devices such as smart wristwatches that track your health and fitness to home automation systems that enable you to control your home over the internet. The growth and impact of the internet of things cannot be overlooked, with various tech companies looking into its future such as Huawei which forecasts 100 billion IoT connections by the year 2025 and the McKinsey Global Institute which suggests the IoT sector may be worth $3.9 to $11.1 trillion by 2025 as well [5] [6].

Problem Statement

In many countries of the world, especially the developing countries, the lack of proper patient health monitoring has become a terror. Statistics show in [7] that more than 40% of adults in Nigeria are estimated to have manageable diseases like high blood pressure, heart diseases and hypertension, but most of these patients have met with various disabilities and in some cases untimely death due to lack of adequate patient health monitoring and insidious manual system of monitoring utilized in the region, as observed in [8]. This project proffers a solution which is an IoT based patient health monitoring system that is capable of monitoring patient's vitals beyond the walls of a health firm.

Aim and Objectives

Aim

This project aims to design and software implementation real-time database of health monitoring system

Objectives

The objectives of the project include:

1.1 Create a Firebase realtime database for transferred data reception and storage.

Literature Review

Real Time Patient Health Monitoring

Patient health monitoring is a process of observing the vital signs of patients with the aim of prognosing ailments to treat them. Traditionally when patients seek medical attention from medical firms, their vitals are first checked by the nurses and then they proceed to the doctors for a diagnosis. The doctors use their discretion to determine whether the patient is to be hospitalized or not. The inpatients (hospitalized patients) are continually monitored by medical personnel of the medical firm while the outpatients are given prescriptions and medical advice then leave. In modern-day hospitals, there are various facilities and equipment that medical personnel use to continually monitor their patients' health. Patient health monitoring can be classified based on target parameters to be monitored/measured in the patients, some of which include:

i. **Respiratory monitoring:** These are the processes that involve monitoring the patients' respiratory system to determine if the blood cells are properly oxygenated and carbon dioxide (CO_2) is adequately passed out of the body. Some respiratory monitoring processes involve: Pulse oximetry, which is the use of an oximeter to measure the saturated percentage of oxygen in the blood (SpO_2) and Capnography, which involves using a capnometer to measure the partial pressure of CO_2 in patients' airways during inspiration and expiration.

ii. **Cardiac monitoring:** These are the monitoring processes that involve the measurement of patients' heart rate and cardiac rhythm. One of the most commonly used means of cardiac monitoring is through electrocardiography (ECG) where electrodes are placed on different parts of the patient's chest to measure/record electrical signals generated from the heart, thus producing an electrocardiograph [9]. Another common means of cardiac monitoring can be through the use of a stethoscope which is an acoustic medical device used to listen for internal sounds in a patient's body, like the heartbeats.

iii. **Hemodynamic monitoring:** Hemodynamics is the study of blood flow.

Hemodynamic monitoring, simply put, are the processes used to measure a patient's general blood circulation. Hemodynamics provides vital physiological information such as arterial blood pressure, tissue perfusion, and oxygenation of tissues and organs. Hemodynamic monitoring systems use catheters which are long medical tubes inserted into the patient, allowing for blood flow observations to take place [10] [11]. Cardiac monitoring and hemodynamic monitoring are usually performed simultaneously, especially for critically ill patients.

iv. **Neurological monitoring:** Also known as intraoperative neuropsychological monitoring or simply, neuromonitoring. It involves assessments of the integrity of various neural structures during surgical operations to prevent unintentional damage to the patient's nervous system. Usually, a neuromonitoring technician is assigned with special monitoring software which he/she uses to detect potential nerve damage that could go unnoticed during the operations. Parameters such as the patient's cranial blood pressure, cerebral perfusion, and blood flow, as well as electric potentials from various nerves of the patient's nervous system and brain, are monitored.

v. **Blood glucose monitoring:** Blood glucose monitoring is the testing and observation of the concentration of glucose in the blood. Traditionally, blood glucose tests are performed through invasive means such as piercing the patient's skin to attain the blood sample to be tested but there are non-invasive means such as Continuous Glucose Monitoring (CGM) which uses sensors that measure the amount of glucose in the interstitial fluid around the patient's skin cells [12]. Glucose monitoring is especially useful in preventing or reversing diabetes and hyperglycemia (high blood sugar). Based on the reviewed works, for an IoT patient health monitoring system to function as demanded, its operation should undergo four phases. These phases include:

i. Data compilation phase: This phase consists of the collection, storing, and accessing patients' health data. Devices used to achieve these include:

a. Sensors which the patients directly interact with, collecting data on their vitals. Wireless sensor networks (WSNs) are the main components of IoT which collect data from the environment or people and transmit the data to the sink nodes.
b. A microcontroller to enable the connection of peripherals such as display screens, and also to convert the analog signals from the sensors to readable digital signals.
c. A local device where health data collected can be sent to and monitored.
d. An IoT server capable of storing collected data that can be accessed through a network (e.g the internet).

ii. Data dissemination phase: This phase involves the use of IoT connectivity technology for proper dissemination of attained data between the sensors, microcontroller, local device and IoT server. Some of the technology used includes:

a. Wireless Fidelity (Wi-Fi) which is used for sending sensed data to a local device for analysis. Wi-Fi is a family of wireless network protocols, based on the IEEE 802.11 protocol standards, commonly used for local area network creation and accessing the internet.
b. GSM/GPRS module used for sending sensed data to an IoT server to be accessed by mobile devices or computer systems that contain an embedded GSM/GPRS module.
c. A wireless router which connects the network of the monitoring system to other networks. With the aid of a wireless router, the sensed data can be sent to an IoT server over the internet.

iii. Data employment phase: This phase involves the access of the collected data from the IoT server. The data from an IoT server can be accessed from:

a. A specialized application programmed to collect the data from the IoT server.
b. A user interface that basically serves as the link between the user and the server.

iv. Security phase: The security of the patient's health data is considered in this phase. It involves the use of secure communication protocols and cyber security tactics to ensure the privacy of patient's health data is maintained.

Methodology

Design Specifications

A. Software design: The specifications of the programs, programming tools and environments used in the project. The software tools and environment used include:

1. Arduino IDE
2. Google's Firebase online database
3. Test website for displaying collected data

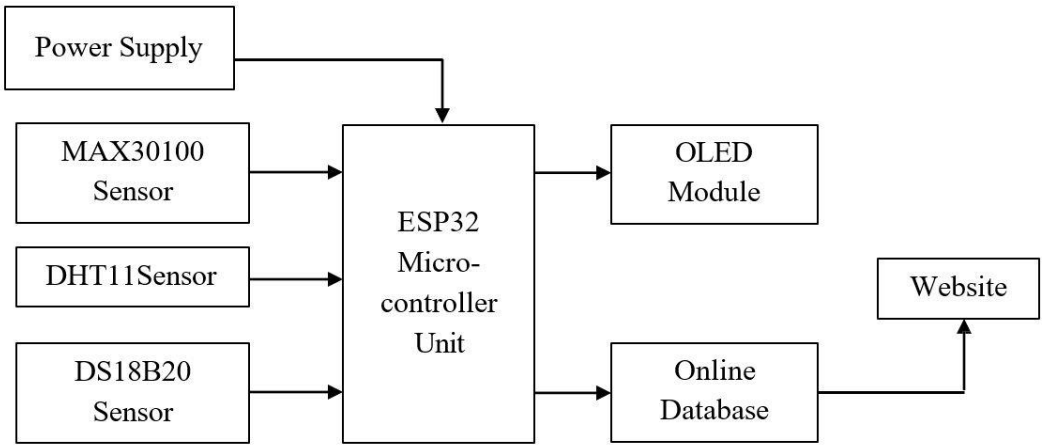

Figure 3.1: Block diagram of the project

3.1 Hardware design

Observing the block diagram provided in figure 3.1, the operations of the hardware components used in the project can be categorized into four stages – power stage, sensing stage, control stage and display stage.

3.1.1 Power Stage

The system is powered by anyone of two means: through a battery supply or through a micro-USB connection to an external power source. A 3.7v battery was chosen as a means to supply power and based on the 3.3v requirement of the ESP32 MCU, both means of supplying power to the system are regulated by the ESP32 by an internal Linear dropout (LDO) voltage regulator.

Voltage regulation: This is the process of providing a near constant voltage over a wide range of loads. As seen in figure 3.2, the ESP32 possesses an AMS1117 Linear dropout voltage regulator that regulates the supplied voltage to about 3.3v. The output voltage from the voltage regulator can be gotten by,

$$VOUT = VIN - VDROP \quad (3.1)$$

where VIN is the input voltage, VDROP is the voltage drop of the LDO and VOUT is the resulting output voltage.

The designed VDROP for an AMS1117 voltage regulator is 1.3v, therefore let VDROP = 1.3v,

Since the desired output is 3.3v, let VOUT = 3.3v,

From equation (3.1) stated above, make VIN the subject and substitute the values for VOUT and VDROP,

$$VIN = VOUT + VDROP$$

$$VIN = 3.3v + 1.3v \quad (3.2)$$

Solving equation (3.2) will result in VIN = 4.6v

From this result a 3.7v battery was chosen since its voltage is within a safe range and yet high enough to power the system.

Also, the same voltage regulation will be performed on power received through the micro USB port, ensuring proper voltages for the microcontroller's operations.

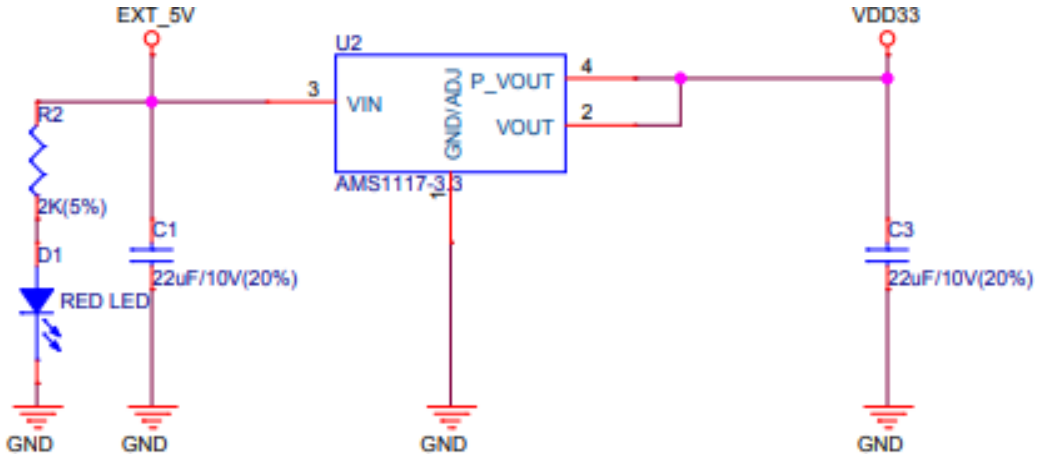

Figure 3.2: Schematic diagram of the power supply segment of the ESP32 MCU

Sensing Stage

Each sensor receives 3.3 volts from the 3v3 pin of the microcontroller unit and all have their negative terminals connected to the ground pin. The MAX30100 is used to sense heart rates and blood oxygen levels from the user. The module uses a simple two-wire I2C interface for communication with the microcontroller, connected to the GPIO pins 21 and 22 which are the I2C pins by default. It has a fixed I2C address: 0xAEHEX (for write operation) and 0xAFHEX (for read operation).

The second sensor is the DS18B20, used to measure body temperature. Designed to utilize the one-wire interface, the 1-wire bus requires that the control signal be pulled high so the master device can pull it low to ask for data, and the slave device can pull it low to give the data. This allows for multiple 1-wire devices on the same "one wire". Without a pull-up resistor between the output and the supply terminals, the DS18B20 sinks close to 0 (zero) amps from the GPIO pins it is connected to due to its parasitic feature. A current draw within 0.5mA to 1mA is desirable so as to be high enough to communicate on the one-wire bus. Let the pull-up resistor be 4.7kΩ and the supply voltage be 3.3v from the microcontroller. Using equation (2.2) the current draw can be calculated.

VCC = 3.3v, RPULL-UP = 4.7kΩ,

IDRAW = 3.3⁄4.7 *X* 1000

Therefore IDRAW = 0.7mA which is suitable for one-wire communication and thus a 4.7kΩ resistor was used as the pull-up resistor for the DS18B20.

The last sensor is the DHT11. The sensor is used to measure environmental temperature and humidity. Similar to the DS18B20, it requires a pull-up resistor of 5kΩ to 10kΩ between the data line and the supply line to ensure

proper communication to the microcontroller. The DHT11 module comes with an in-built 5.1kΩ pull-up resistor. Following similar calculation steps performed for the DS18B20,

Let VCC = 3.3v,

RPULL-UP = 5.1kΩ,

$I_{DRAW} = {}^{3.3}/_{5.1\ X\ 1000}$

∴ IDRAW = 0.64mA, an acceptable value for the microcontroller and the DHT11 to establish proper communication.

Firebase Realtime Database

Firebase is an online application development platform developed by Google which enables the development of Android, iOS and web applications. Serving as a Backend-as-a-service (Baas), it provides a variety of tools and services to aid in application development. Its first and most popular service is the Firebase Realtime Database which is an API that allows for synchronization and storage of application data to Firebase's cloud storage. Following a NoSQL database structure, the Firebase realtime database offer high scalability, flexibility, functionality and speed; making it a satisfactory option to IoT projects.

Flowchart

The flowchart depicted in figure 3.6 describes the sequence of processes and decisions the system undergoes as instructed in the code.

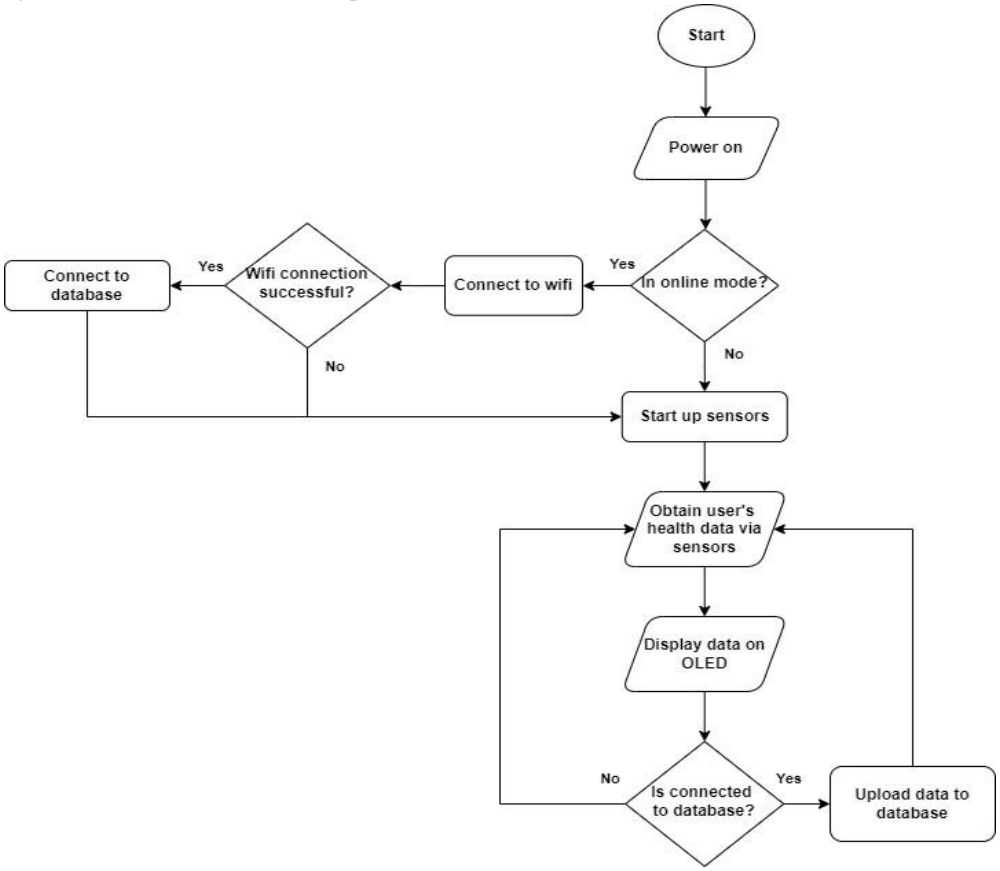

Figure 3.6: Flowchart of the system

Methodology

The construction of the IoT based patient health monitoring system was done using soldering and coupling of the active circuit. The soldering was done on the PCB using 40 watts soldering iron, and the components were properly arranged in accordance to the circuit diagram as seen in figure 3.4.

Soldering

This is the connection of a conductor or component to a circuit board using a soldering iron and a soldering lead wire. This part was done after the initial testing was conducted on the beard board.

PCB Manufacturing

The PCB used in this project was manufactured using the Toner transfer method while making use of the flowing equipment:

1. LaserJet printer
2. Electric iron
3. 4" x 6" sticker
4. Piece of copper coated sheet
5. Liquid Ferric chloride (CI3Fe)
6. Mini drill machine
7. Liquid rosin

The following steps are taken when using the Toner transfer method;

1. Take a sticker, and peel off its backside and paste off its backside and past its opposite side to the stickers.
2. Now open the circuit layout and change some printing settings to match the paper and print it.
3. Sticker paper is very slippery, and it is difficult for printer to pick it, so push a little inside while printing job is being started.
4. Now cut a piece of copper coated sheet according to your circuit size and clean it using scotch brite and water.
5. Use steam iron to transfer the circuit layout from the sticker paper to the copper coated board. Apply a lot of weight on it for 5 to 10 mins.
6. Now peel off carefully.
7. Dip the board in the ferric chloride; be sure to wear eye protection, rubber gloves and protective suit when handling chemicals.
8. Stir for 15 to 20 mins or until the naked copper is removed
9. Wash with water and scratch it using scotch brite
10. Make the holes using the mini drill
11. Apply a thin layer pf liquid rosin on it will keep it safe from rusting.
12. The PCB is ready for use.

3.1.2 Assembling of components

The number of components used will determine the design of the PCB and the size.

1. Begin by fitting the components into their appropriately designed spaces.
2. Make sure polarized pieces are oriented accordingly.
3. When designing the PCB ensure there are no intersection of cables in the circuit
4. Do no put components at different angles from 0 to 90 degrees.
5. Ensure the excess metal under the board is cut off to a reasonable length after soldering.
6. Ensure to connect the 3.7V voltage source at the right polarity.

Results and Discussions

Implementation

The implementation of this project was majorly carried out in two stages. These include;

Software Implementation

Software implementation

The Arduino IDE was used to write the code that instructs the microcontroller on the processes to perform.

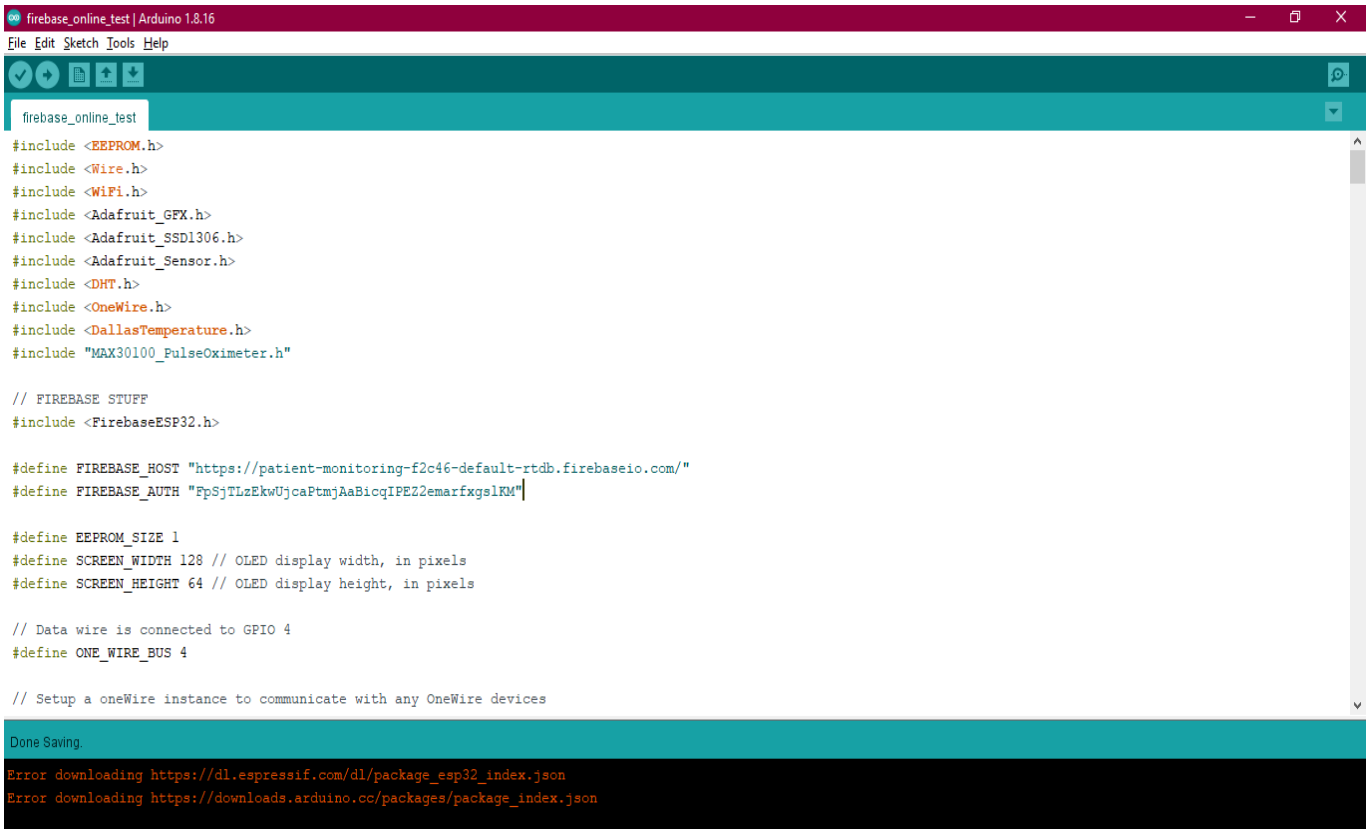

Figure 4.1: A snippet of the code

Explanation of code

The code starts off by calling the necessary header files that contains the functions that are integral to its successful run. This is done with the '#include' preprocessor directive. The header files called include:

i. Wire.h: Contains functions that allow for I2C device communications.

ii. WiFi.h: Contains functions that enable the ESP32's Wi-Fi capabilities.

iii. EEPROM.h: Contains functions that allow for the utilization of the ESP32's flash memory.

iv. DHT.h: Contains functions that allow for the basic functioning of the DHT11 sensor.

v. Adafruit_GFX.h: Contains functions for the proper functioning of the graphical display for the OLED.

vi. Adafruit_SSD1306.h: This contains the functions for the operating of components that use the SSD1306 integrated circuit chip, like the OLED.

vii. OneWire.h: This contains functions that enable components that utilize the one wire protocol in their means of operation.

viii. DallasTemperature.h: Contains the necessary functions for the retrieval of readings from all Dallas made components, such as the DS18B20.

ix. MAX30100_PulseOximeter.h: This contains functions necessary for the operation of the MAX30100 sensor.

x. FirebaseESP32.h: This header file contains the functions that allow for the ESP32 to transmit sensed data to Firebase's online database.

Immediately after the header files are called, some constant values are defined with the '#define' preprocessor directive. These values will not change throughout the entirety of the programs running. These constant values include the particular GPIO's the components connect with the ESP32, the display height and width for the OLED, the size of the ESP32 flash memory to be used and the details for connecting to the Firebase online database. Some other variables are declared in this section as well. These variables are global in scope.

The main part of the code begins at the 'void setup ()' function block. It starts off by setting up the ESP32 flash EEPROM memory and a conditional statement to check the memory if the user had set the system to offline or online mode – 0 for online and 1 for offline. The OLED's SSD1306 chip is started with the 'display.begin(SSD1306_SWITCHCAPVCC, 0x3C)' statement and then the OLED displays my name and matriculation number as instructed.

After the display, the code then states that the ESP32, if in online mode, should try to connect to the wifi connection whose details (SSID and password) have already been stated in the code earlier. This is done with the 'WiFi.begin(ssid, password);' statement. Following the code, if the connection is successful, the OLED displays 'Connected to server', and the Firebase is started and setup. If the connection was not successful, the OLED displays, 'Could not connect to the internet', then the ESP carries on like it was in offline mode. The rest of the 'void setup ()' block just starts up the sensors, using the 'dht.begin();' and the 'pox.begin();' functions for the DHT11 and the MAX30100 respectively.

After the 'void setup ()' block ends the 'void loop ()' begins. The 'void loop ()' ensures continual reiteration in the code unless deliberately prevented from doing so by the programmer. All that lies within the 'void loop ()' block are things that need be perpetually checked or executed. Inside the block the GPIO pin 5 of the ESP32 is constantly being checked to know if the push button has been pressed to switch between offline and online mode of operation. The conditional statement around this is set so that if the push button allow current to enter the GPIO pin 5, the variable in which stores the offline-online mode state in the stored is changed either from 0 to 1 (offline to online) or from 1 to 0 (online to offline). The next lines of code updates the MAX30100 sensor and store the readings from the various sensors in their respective and appropriately named variables. A block of code which sets up a timing function is used to time the display of sensor data onto the OLED module. This is done with the use of the millis function which is a function that starts counting at the startup of the microcontroller and does not stop till the MCU is disconnected from power or reset. Coupling the millis function with a variable, timing control is achieved in the code. The 'n' variable is what is checked to know what the OLED should be displaying at a time. Following the timing function, after three seconds, the 'n' variable changes and so does what the OLED displays. When n = 1, it OLED shows a request to prompt the user to put his/her finger over the MAX30100 sensor to take readings, when n = 2, it displays the DHT11 sensor readings, when n = 3, it displays the DS18B20 temperature readings and then it goes back to when n = 1. There is an added condition that is checked when displaying the sensor readings and that is if the MAX30100 is not taking any readings. If the MAX30100 is taking any readings, all other sensor readings are removed from the display and the MAX30100 readings are show on the OLED. This is done to prioritize the heart rate and SpO2 because if the user is

placing his/her finger over the MAX30100, he/she is truly eager to know those particular set of data at the moment. After three seconds of no activity from the MAX30100, the OLED resumes displaying the other sensor data.

Lastly, still within the 'void loop()' block, a counter variable is used to control the timing of transmission of the sensed data to the Firebase database. This block is only considered if connection to the internet was successful. The 'count' variable increases every time the 'void loop()' block runs. When this variable reaches 100 (starting from 0), data is sent to the database in the form of json files. The json files are created with the 'json.set();' function before they are sent to the database. Also in this block, a condition is executed to allow for stored data when the system was offline to be sent to the database when the system next connects to the database.

Database setup

The database used was the online realtime database service from Google's Firebase. A user account was created and the specifications of the desired database were specified through the forms provided on their website. After the account was created and the realtime database was established, the server and database details were added to the ESP32's code so it can be able to access the newly created database and transmit the sensor data.

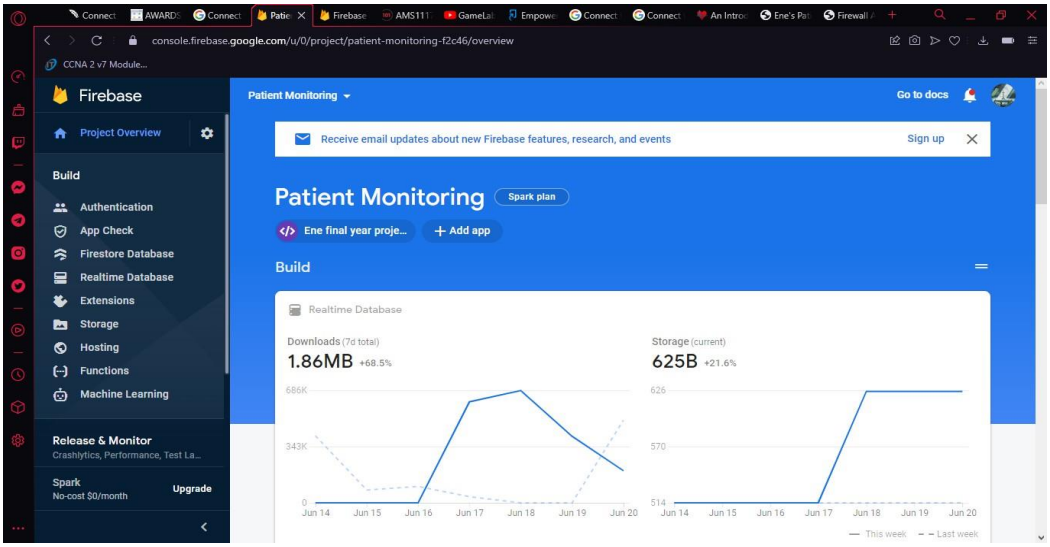

Figure 4.2: A screenshot of the Firebase console

Packaging

Packaging of the system was performed for convenient mobility and professionalism. The packaging was done using a white plastic box referred to as a double gang pattress box. The pattress box came with some openings but not in usable locations, as openings were needed for the OLED display module to be viewable, the MAX30100 to be accessible, the DS18B20 to be accessible and the push button to be usable while the whole circuit remained in the box. Thus, openings in were created in the box at strategic locations allowing for the components listed above to be accessible to the user. Also, openings were created for the slide switch and the micro USB port of the ESP32 so as to allow the user to be able to turn on/off battery power supply and to allow the system to be powered through a micro USB connection to an external power source.

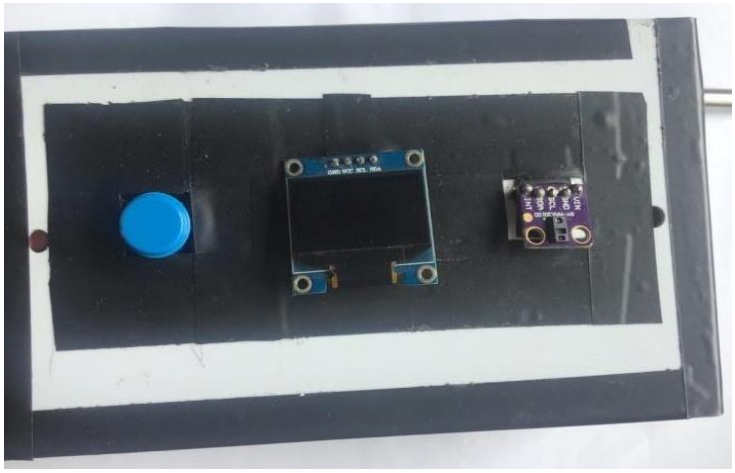

Figure 4.3: The fully constructed proposed system

Testing and Results

The hardware components, after being put together and packaged were tested with the code written for the ESP32 through the Arduino IDE. As the microcontroller received power, it first displayed my name and matriculation number, and then it prompts the user to place a finger over the MAX30100 to check his/her heart rate as shown in figure 4.4. After three seconds of idleness, it then displays the room temperature and humidity. After another three seconds of idleness, it displays the temperature readings from the DS18B20 sensor. To test the proper functioning of the program, I placed my finger on the MAX30100 sensor, and just as programmed, it displayed my heart rate and blood oxygen saturation level on the OLED screen. I also held the DS18B20 probe for a short while, giving me a temperature reading of 35ºC. I compared the averages of the data attained by the system to those of standard medical devices which are shown in the table below.

Table 4.1 Attained Data Comparison

	Data from system	Data from standard medical devices
Heart/Pulse rate	81.5	89.2
SpO2	94%	94%
Body temperature	35ºC	36.4ºC

Carrying out an analysis of the data comparison it is seen the heart rate values and the temperature values attained by the system average slightly lower than those of the standard medical thermometers and pulse oximeter sensors. Regardless, the margins of variation are not too significant and can be accounted for by the users and medical practitioners.

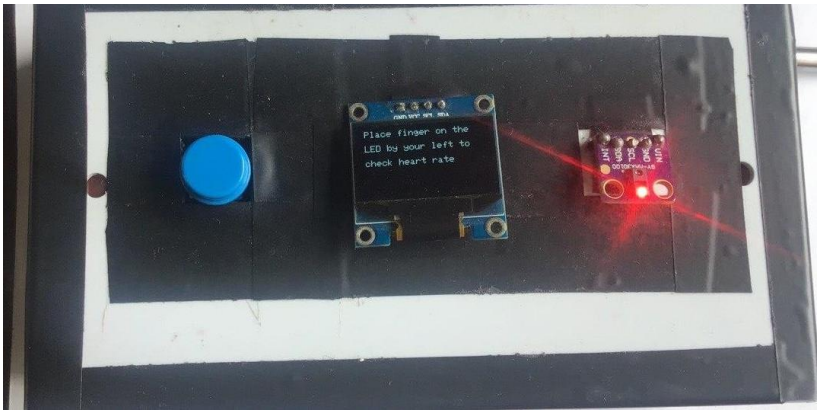

Figure 4.4: The system in operation

As seen in figure 4.5, the data collected by the system was successfully sent to the database. Since the database operates in real-time, the data was sent almost instantly as long as the internet connection was stable.

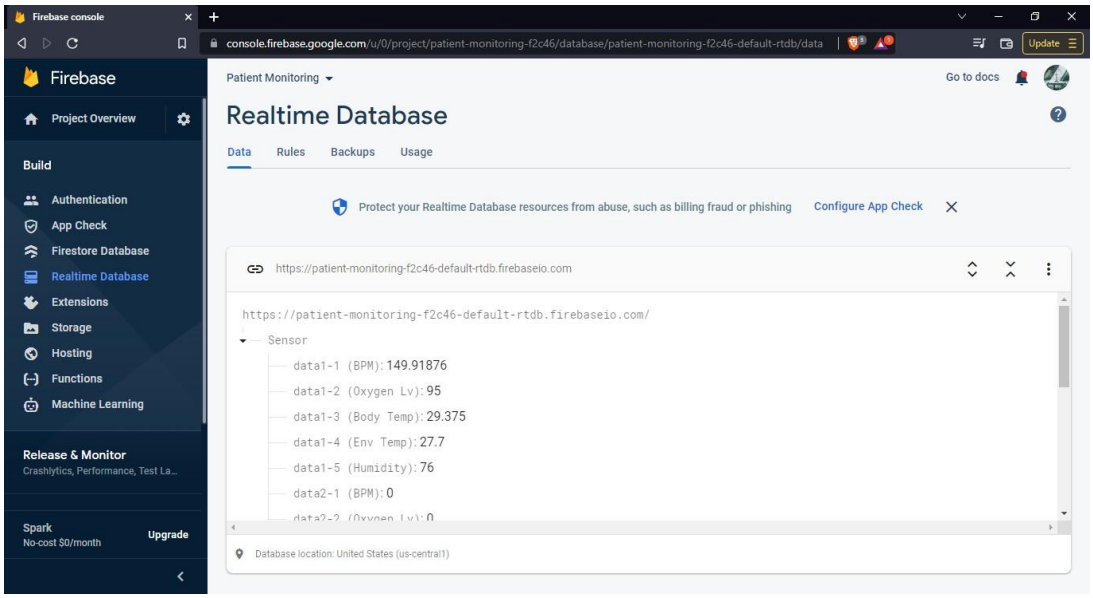

Figure 4.5: Sensor data in the database transferred from the system

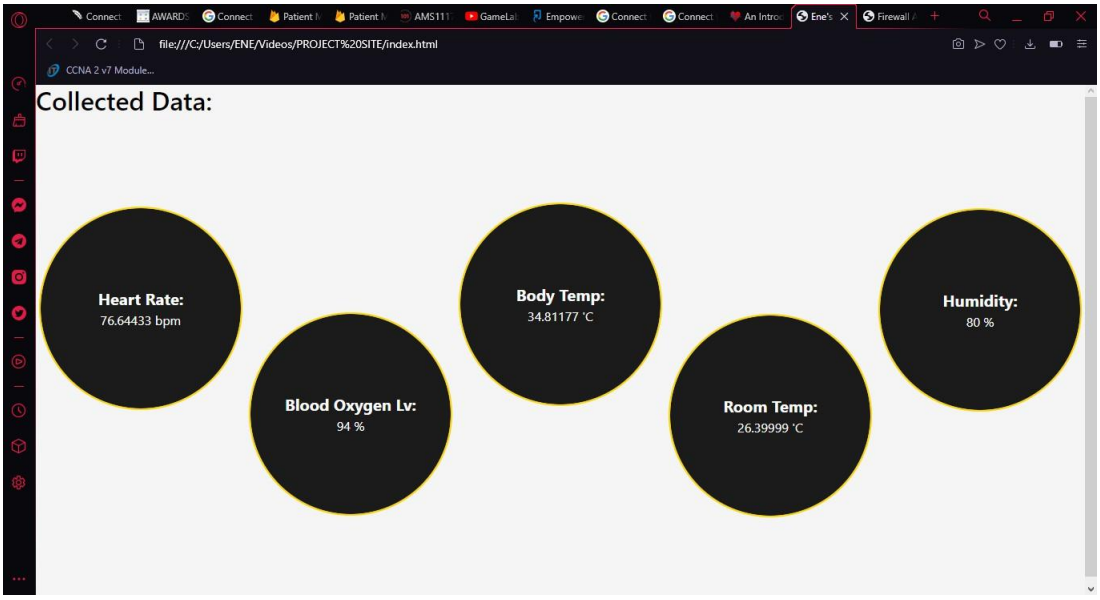

Figure 4.6: A screenshot of a test website with attained data from the database

As shown in figure 4.6, a live webpage was able to display data collected from the realtime online database which was sent from the implemented system. The webpage shows the user's heart rate, blood oxygen level, body temperature and the temperature and humidity of the environment around the user.

Conclusion

The main purpose of the project was to design a real-time patient health monitoring system that could monitor patients' health vitals outside the hospital, to allow for continual monitoring regardless of the patients geographical location. Three sensors were utilized, the MAX30100, the DS18B20, and the DHT11 which collected heart rate and blood oxygen levels, body temperature, and environmental temperature and humidity respectively. With the aid of the ESP32 microcontroller, the attained data from the sensors were able to be transferred to an online database. The database that was utilized was the Firebase which enables easy retrieval of data from the ESP32 and easy access to the data through a website, from anywhere in the world.

5.1 Recommendations

My recommendations for future projects include:

i. More health parameters to be monitored to allow for a more effective patient monitoring system.

ii. Increased number of health data to be stored for better analysis of patient by medical personnel.

iii. Integrate a battery charger to enable the batteries to be recharged when drained.

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