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An IoT-Based Patient Health Monitoring System

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Abstract

The study delved into an IoTs based patient health monitoring system. Using inadequate and inconsistent health monitoring techniques and technology, the issue of sudden deaths has become of great concern. 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 underlying health conditions.

***Keywords**: Internet of Things (IoT), Monitoring, System, Sensor.*

Introduction

The everlasting desire for good health has brought about the rapid development of medical techniques and technology, making the healthcare industry one of the largest and fastest growing industries in the global economy [1]. 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].

The health sector is one of the biggest beneficiaries of technological innovation as healthcare institutions rely more and more on the various technologies to properly manage, monitor and deliver quality patient care. One of the most significant advancements is the Internet of Things (IoT). IoT is a network of interconnected computing devices that can gather and exchange data over communication networks without human intervention. These smart gadgets normally have sensors that collect information and send it to an IoT gateway, which then passes the data across networks like the Internet. The Internet of Things has emerged as a disruptive technology that has enabled interconnected devices to acquire, process and share information efficiently. Consequently, IoT has become an intelligent network of machines and gadgets that can communicate smoothly to provide better healthcare services and operational efficiency [4].

The recent surge of interest in IoT technology has resulted in a wide range of devices being available to consumers, businesses and individuals - from small devices such as smart wristwatches that track your health and fitness to home automation systems that allow you to control your home over the internet. The internet of things is growing and its impact cannot be ignored, with several tech companies looking at its future such as Huawei which predicts 100 billion IoT connections by 2025 and the

McKinsey Global Institute which estimates that the IoT sector may be worth \$3.9 to \$11.1 trillion by 2025 as well [5] [6].

Problem Statement

Poor patient health monitoring is a major healthcare concern in many regions of the world, particularly in developing countries. Statistics released in [7] show that over 40% of adults in Nigeria are affected by treatable health issues such as hypertension, heart disease and excessive blood pressure. However, the absence of health monitoring and the continuous dependence on inefficient manual monitoring techniques lead many patients to suffer from serious consequences, permanent disability, or even premature death [8]. To solve this problem, this study offers an Internet of Things (IoT)-based patient health monitoring system that continuously monitors patients' vital signs beyond the physical confines of healthcare facilities.

Aim and Objectives

Aim

This project aims to design an IoTs based patient health monitoring system

Objectives

The objectives of the project include:

i. Design a health monitoring system able to collect health data from users.

ii. Create the logic for proper system operation.

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

iv. Implement and test the designed system.

Literature Review

The Internet of Things

Internet of Things (IoT) is a kind of network which connects any device to the internet based on well defined protocols through information sensing equipment to carry out information exchange and communication. The abilities of IoT devices are to gather specific data and to transfer the data to other IoT devices using networks such as Bluetooth and the internet. IoT devices can function in four major connectivity models:

i. **Device-to-device connectivity model**: The connection paradigm is that devices are connected directly and communicate with each other. Such gadgets are capable of communicating over several sorts of networks, including the Internet. This paradigm is extensively used in home automation systems, where the IoT devices connect with short data packets of information and low data rates.

ii. **Device-to-cloud connectivity model**: In a device-to-cloud connectivity model, devices communicate with one another through an internet cloud service. Devices that operate using this model usually transmit data to a cloud database, through an Internet Protocol (IP) network, where the data can be accessed and analysed by another device. Communication mechanisms such as Wi-Fi or wired Ethernet connections are used to establish a connection between the device and an IP network.

iii. **Device-to-gateway connectivity model**: The device-to-gateway paradigm, also known as device-to-application layer gateway model, introduces an application layer gateway (ALG) that functions as an intermediary between the IoT devices and the cloud service. The ALG (or local gateway) provides a range of services including data security, communication protocol translation, and integrating new devices into the IoT framework.

iv. **Back-end data-sharing model**: This model is about the communication architecture which enables the users (humans) to export and analyse the data stored in the cloud service database. The data which was uploaded to the cloud database by other IoT devices. This approach is an extension of the device-to-cloud concept in which the uploaded data can be accessed for analysis by the users. In a device-to-cloud approach, each IoT sensor uploads data in a stand-alone data silo (data that is normally inaccessible to other elements of an IoT framework/system); but, with a solid back-end data-sharing architecture, users can access data posted by various IoT devices on the cloud database.

Sensors

A sensor is a device designed to detect or measure physical conditions in its surrounding environment and convert them into data that can be interpreted by humans or electronic systems. Electronic sensors are specialized sensing devices that transform measured physical parameters into electrical signals for processing and analysis. Generally, electronic sensors are classified into two main categories:

i. Analog sensors: These types of electronic sensors measure external parameters and produce a continuous voltage (signal) as output. Their outputs can range from 0v – 5v; 0v – 3.5v

(Low logic) and 3.5v – 5v (High logic).

ii. Digital sensors: On the other hand, digital sensors measure their specified external parameters and produce a discrete pulsating voltage as output. Their outputs are binary (0s and 1s).

Microcontrollers

A microcontroller is a small integrated circuit designed to control one or more functions of an embedded system. It combines a CPU, memory and input/output (I/O) interfaces on a single chip, enabling efficient control of electrical devices. It is also known as a microcontroller unit (MCU) or embedded controller. It is widely utilized in applications such as cars, robotics, office equipment, medical devices, wireless communication systems, vending machines and household appliances. Popular microcontrollers are Arduino Uno and ESP32 as seen in Figure 2.2.

The microcontroller then processes the data it has received via its input / output peripherals using its central processing unit (CPU). Program memory contains instructions to process incoming data and perform certain functions, while data memory contains temporary information. The microcontroller, after processing the information received, communicates with its attached peripherals to perform the appropriate actions. The main components of a microcontroller are as follows:

i. **The processor (CPU):** The CPU is like the brain of the device. It receives and executes a number of commands which control the working of the microcontroller. It involves basic arithmetic, logic, and input/output (I/O) operations. It also transmits commands to other components of embedded system through data transfer procedures.

ii. **Memory:** A microcontroller uses memory to store the data that the processor receives and uses to react to instructions it has been configured to do . There are two primary types of memory, the program memory that saves long-term data on the instructions to be carried out and the data memory that stores temporary data.

iii. **I/O peripherals:** The processor's interface with the outside world is provided through its input and output devices. The processor receives data from the input ports in binary format. The output devices, which carry out functions not under the control of the microcontroller, get the data from the processor and are given the necessary instructions.

Figure 2.2: Examples of microcontroller units - Arduino Uno (left), ESP32 (right)

Review of Related Works

Various works on remote health monitoring and telemedicine have been published that explain extensively how systems can be joined together to help monitor patients beyond the walls of the medical firms.

In [13], a remote monitoring system that uses temperature and light sensors working in conjunction with an android smartphone application software is described. The array of sensors is connected to an Arduino board which is a microcontroller board used for creating programmable circuits. The Arduino board contains a Bluetooth chipset, allowing for connectivity between the sensors and the smartphone application.

In [14] the authors propose a monitoring system that is based on modular Embedded Network Gateway Servers (ENGS), where the sensory devices can upload acquired data without the need of a relay network. Based on the dynamic system concept description, the monitoring system is able to switch between two modes depending on if the wearable sensory devices are within the ENGS range – the pull mode and the push mode. The pull mode is activated if the sensors are out of ENGS range making collected data to be stored in wearable device. On the other hand, the push mode activates once the ENGS can pick up the wearable device signal, allowing collected data from the sensors to be transmitted to it. The diagrammatic conceptualization of this system can be seen in figure 2.3.

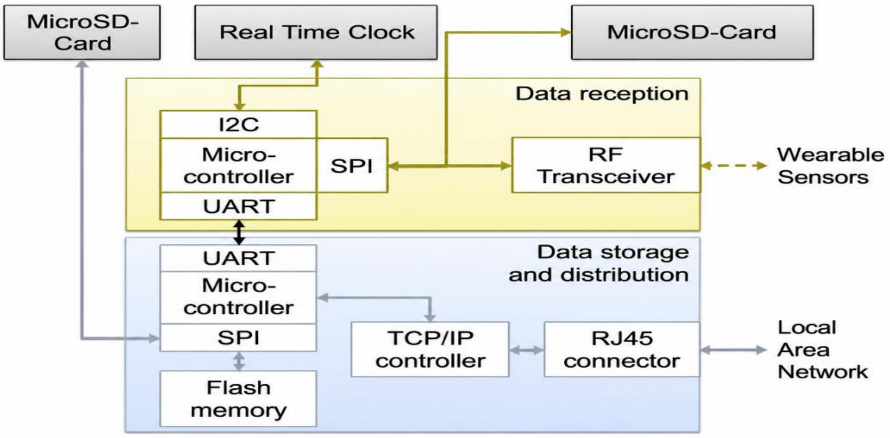

Figure 2.3: System concept of an embedded network gateway server Source: Adapted from [14]

In [15], the Advanced Care and Alert Portable Telemedical Monitor (AMON) project was introduced as a wearable health monitoring and alert solution for high risk cardiac patients. As seen in the system overview in Figure 2.4, the project was designed to collect, analyze and send patients' vital signs to a medical center over a cellular communication network. The planned AMON system has two primary components: a wrist-worn monitoring unit and a fixed unit at the medical centre. The wearable unit includes sensors to measure the blood oxygen saturation, blood pressure and heart rate, and a Global System for Mobile Communication (GSM) transceiver that sends the physiological data to the stationary unit for ongoing monitoring and medical assessment.

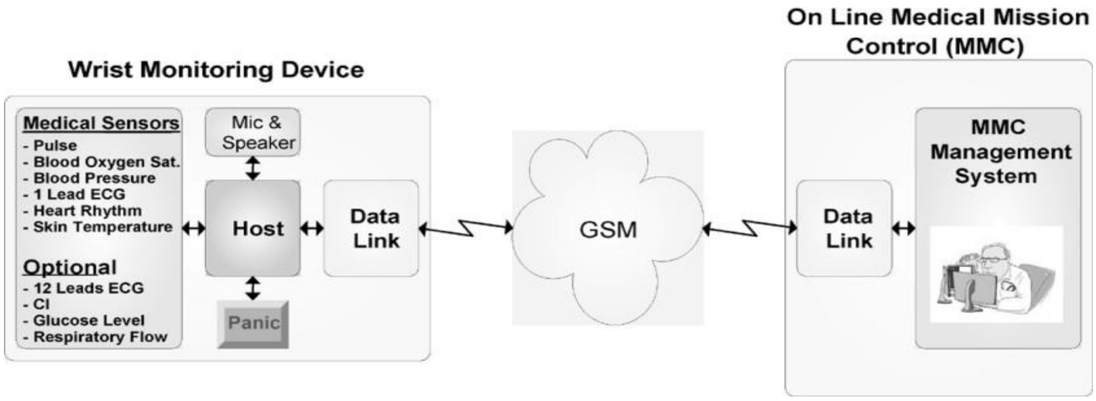

Figure 2.4: System overview of the AMON monitoring system Source: Adapted from [15]

[16] MEDiSN is a wireless sensor network for monitoring physiological data of patients in hospitals and disaster situations, which uses a two-tier system architecture and a rate control mechanism to reliably meet quality of service (QoS) criteria in large scale networks. The architecture of MEDiSN as illustrated in figure 2.5 comprises of physiological monitors (sensors) that gather patient data, relay points that are responsible for relaying the data and a gateway that provides commands, collects and delivers the physiological data to the MEDiSN server database.

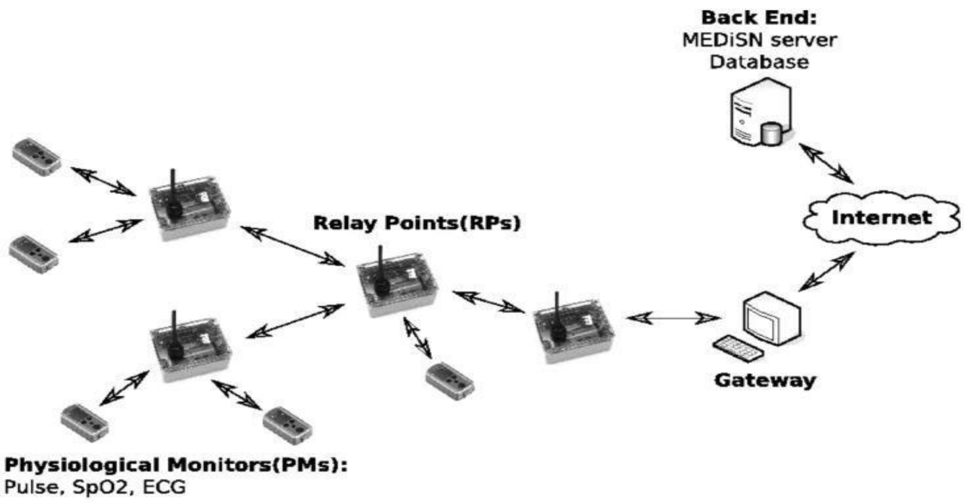

Figure 2.5: The MEDiSN system architecture Source: Adapted from [16]

In [17] a remote health monitoring system for heart failure patients, called WANDA, was unveiled. The system consists of a smartphone-based data gathering gateway, an internet scale data storage platform, and a backend analytics engine for diagnostic and predictive purposes. WANDA leverages Amazon's cloud services to securely and reliably store and manage patients' health data. It also uses Amazon SimpleDB to store structured data, such as patient records and sensor data. By employing SimpleDB, remote healthcare applications can obtain improved database flexibility, scalability and effective data management.

Methodology

Design Specifications

A design specification is a detailed engineering document that provides explicit information regarding a product or a process. Design specifications are aimed at providing clear and unambiguous definition of the functions, features and performance of a product or process. The proposed system design of this project is divided into two:

A. Hardware design: The specifications involving the principal hardware components; components of which include:

   1. MAX30100 heart rate and pulse oximetry sensor
   2. DS18B20 temperature sensor
   3. DHT11 temperature and humidity sensor
   4. OLED display module
   5. ESP32 DEV KIT V1 MCU

B. 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

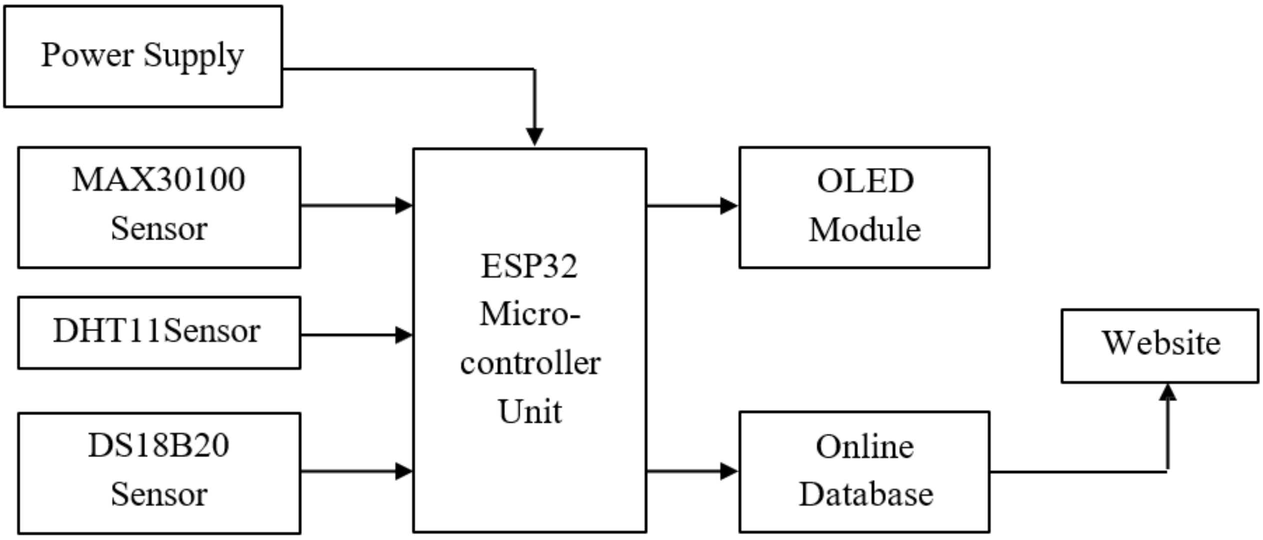

Figure 3.1: Block diagram of the project

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.

Power Stage

The system is powered by any one 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,

$$V_{OUT} = V_{IN} - V_{DROP} \qquad (3.1)$$

where V_{IN} is the input voltage, V_{DROP} is the voltage drop of the LDO and V_{OUT} is the resulting output voltage.

The designed V_{DROP} for an AMS1117 voltage regulator is 1.3v, therefore let V_{DROP} = 1.3v,

Since the desired output is 3.3v, let V_{OUT} = 3.3v, From equation (3.1) stated above, make VIN the subject and substitute the values for VOUT and VDROP,

$V_{IN} = V_{OUT} + V_{DROP}$

$V_{IN} = 3.3v + 1.3v$ (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.

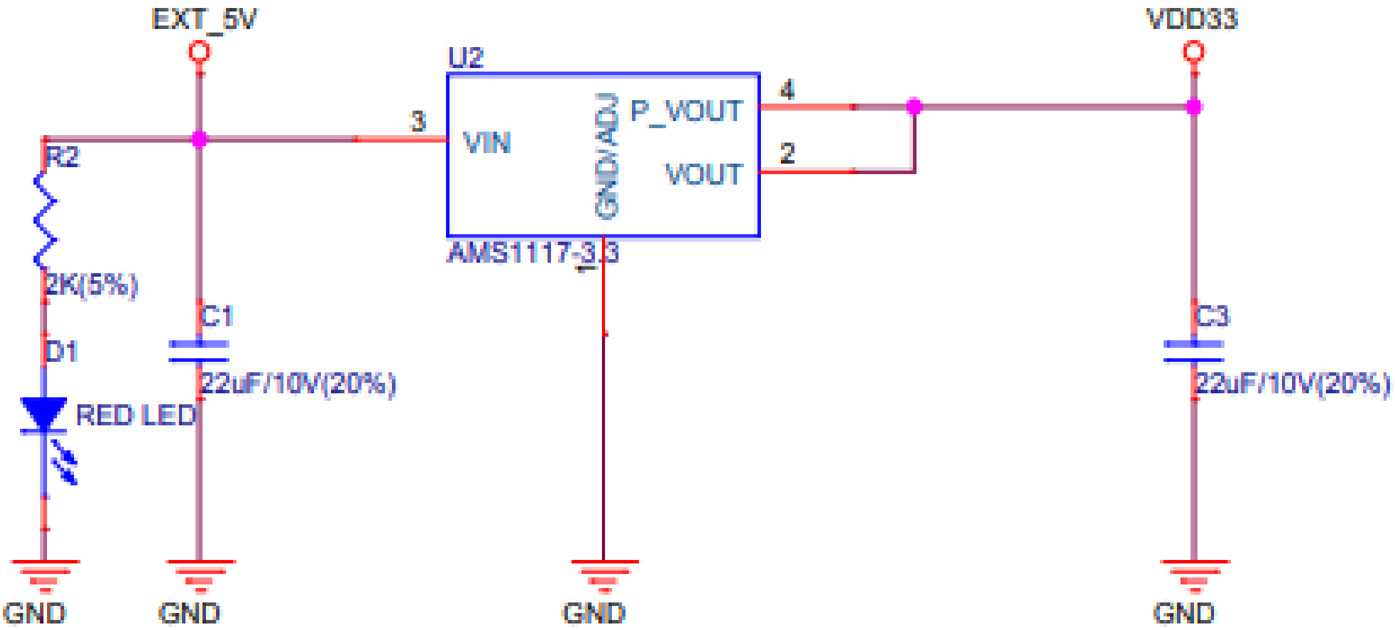

Figure 3.2: Schematic diagram of the power supply segment of the ESP32 MCU

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 rate and blood oxygen levels from the user. The module communicates to the microcontroller over a simple two-wire I2C interface attached to the GPIO pins 21 and 22, the default I^2C pins. It has a fixed I2C address: 0xAEHEX (write operation) and 0xAFHEX (read operation).

The second sensor is the DS18B20. It is utilized for measuring the body temperature. The 1-wire bus, which is intended to operate on the one-wire interface, requires the control signal to be pulled high for the master device to draw it low to request the data and for the slave device to pull it low to provide the data. This permits several 1-wire devices to be connected 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,

$$IDRAW = {}^{3.3}/_{5.1} \, X \, 1000$$

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

Control Stage

The ESP32 MCU is used as the control system, communicating with the other components and transmitting their data to the display module and the online database if connected to the internet.

The ESP32-D0WDQ6 chip is programmable and was programmed via Arduino Integrated development environment (IDE) using C++ programming language. It supports Wi-Fi module and dual core processor. It can implement TCP/IP, full 802.11 b/g/n/e/i WLAN MAC protocol and Wi-Fi Direct requirements. The ESP32 reads and runs the scripts sent to it, accesses the internet, connects to the online database, collects data from the sensors, and finally uploads the sensed data to the database.

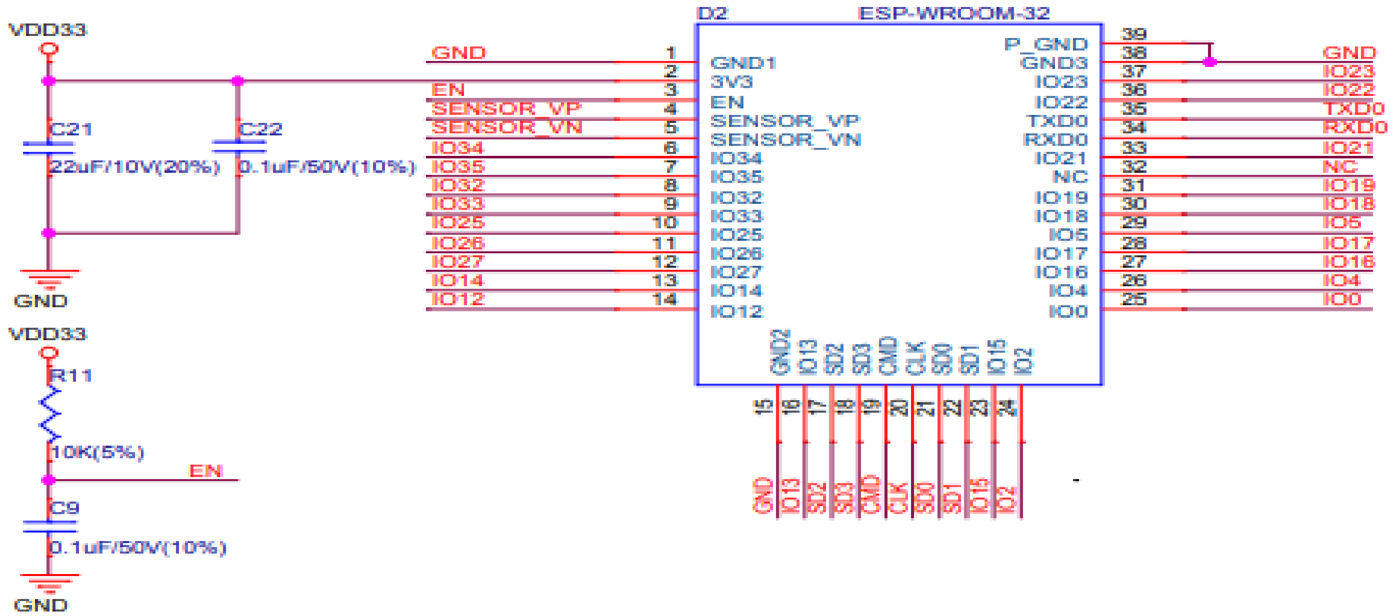

Figure 3.3: Schematic diagram of the ESP32 module

Display Stage

The ESP32 is told to send the sensor data to an OLED display module, making it easy for the user to see. The 0.96 inch OLED display module contains the SSD1306 chip which is a single-chip CMOS OLED/PLED driver and controller. The SSD1306 has built compared control, display RAM and oscillator. This lowers the amount of external components and power consumption. It has 256 brightness control levels. General MCU with hardware selected 6800/8000 series compatible Parallel Interface, I2C interface or Serial Peripheral Interface sends Data/Commands. Like the MAX30100 sensor, the module communicated with the microcontroller using the I2C interface bus. The MAX30100 has its own unique I2C address so that communications to the microcontroller does not interfere with its functionality. After uploading the application to ESP32, the OLED was used to display the sensor data, changing each sensor data every 3 seconds.

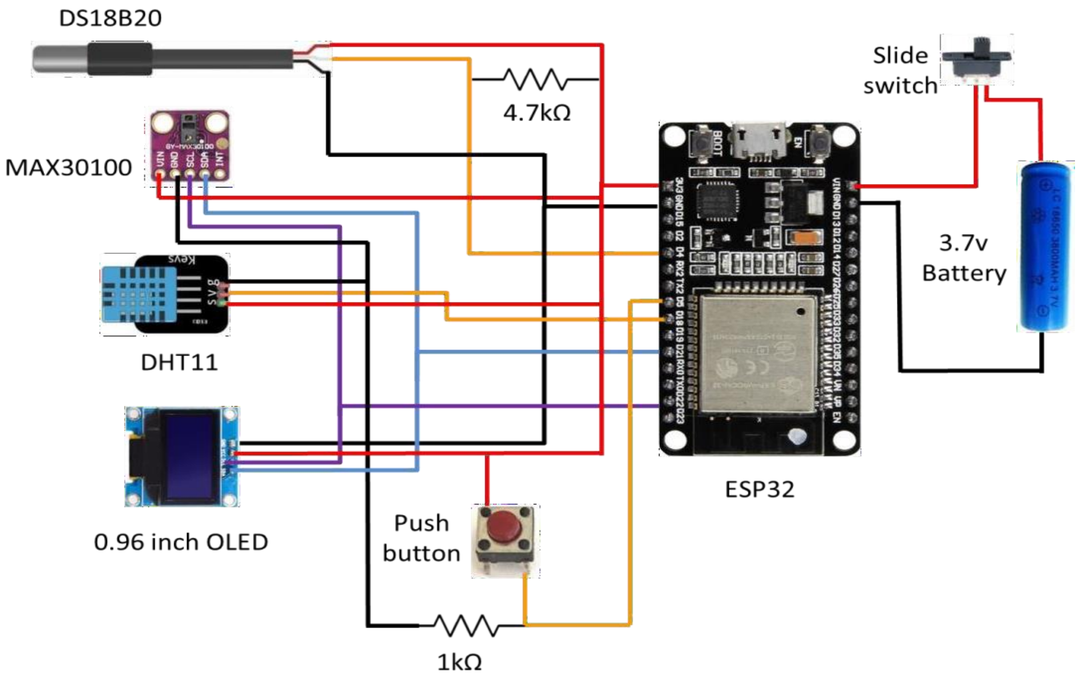

Figure 3.4: Circuit diagram of the project

Results and Discussions

Hardware Implementation

The implementation of the hardware involved the connection of a MAX30100 sensor, a DS18B20 temperature sensor, a DHT11 sensor, a 0.96 inch OLED screen module, the push button, the slide switch and the battery to an ESP32 as already designed. Before the complete circuit was constructed, each component was tested with the ESP32 to look for any underlying faults that may cause issues later on. This was achieved by attaining each components sample program from the internet, uploading the programs to the ESP32 and testing each one with the microcontroller consecutively. This test was carried out on a breadboard and after proving no underlying faults in the components; the entire circuit was then constructed and tested again before transferring the circuit to a printed circuit board.

Conclusion

The main purpose of this project is to design a patient health monitoring system based on Internet of Things (IoT) that can monitor patients' vital parameters continuously out of hospital environment anywhere in the world. The system used three sensors such as MAX30100 for heart rate and blood oxygen saturation measurement, DS18B20 for body temperature measurement, and DHT11 for environmental temperature and humidity measurement. The data from these sensors were sent to an internet database using the ESP32 microcontroller. The cloud database selected for this work was Firebase because it allows effective data storage, smooth retrieval from the ESP32 and remote access to the health information of the patient through a web based platform from any place.

In this report, an introduction to patient health monitoring and the internet of things was stated, a background study as well as the aims and objectives of this particular project. Thereafter a literature review of various previous works that centered on the similar topic or having similar concepts.

Recommendations

i. Reduced size and weight of the monitoring system to allow for greater convenience, in turn encouraging patients to more frequently use the system.

ii. Integration of a GSM module to allow for an extra option of transmission of health data for cases where patients lack access to frequent and/or decent internet connection.

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