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A Smart Monitoring System for Comatose Patients

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Abstract

In coma, the state of unconsciousness, the patient needs constant monitoring of several parameters because it is a critical condition. The vital parameters of these patients must be monitored continuously, so to keep track of their condition. It might be impossible to manually handle the monitoring of numerous coma patients. In the era of technology, the importance of the Internet of Things (IoT) is expanding on the technical, social, and economic fronts towards humankind. A real-time database system has been proposed, by combining IoT and monitoring system that can monitor and store data on different parameters of a patient's various characteristics including heart rate, ECG, temperature, urine level, movement, SpO2 and eye movement or blinking. It can detect as well as store all the data of respective patient. Two methods have been implemented to display the respective parameters of coma patient, one is the developed mobile application which displays all the parameters (heart rate, ECG, temperature, urine level, movement, SpO2 and eye movement or blinking) and the other is LCD which displays only 4 of the respective vitals (heart rate, temperature, urine level and SpO2). In the event of any anomaly, both displays have the ability to generate alerts. At the end the outcomes of the smart monitor presented on LCD ceases to display the parameters in favor of the alert note while the mobile application generates an alert notification. These results verified using a patient monitor by (Nihon kohden). It is concluded that a human health monitoring system based on the Internet of Things can give individuals daily health management, which is essential for raising the standard and quality of healthcare services.

Keywords: Monitoring system, Coma patients, Biomedical devices, IoT, Remote monitoring, Database.

INTRODUCTION

A coma is a profoundly unconscious state. A coma can develop as a result of a disease or accident, such as a head injury, or as an aggravation of an existing condition. Critically ill individuals must have their vital signs measured at least once every 15 seconds until their situation stabilizes. As a result, coma patients require different monitoring techniques than healthy patients. IoT is a technology that links things and promotes human connection for a better quality of life. The most significant of the many uses that the IoT has enabled globally is the healthcare industry. This project involves attaching a microcontroller-based system with the proper biosensors to the patient to continuously monitor their heartbeat, limb movements, temperature, blood oxygen levels, etc. while they are in a coma. All the parameters are continuously monitored. The database system used in the prototype can save patient data, which medical professionals can access online and through a mobile app.

In the coma state, it is quite difficult for the hospital staff to manually monitor all the parameters of the patient constantly. The coma patient is alive but cannot respond or react to the surroundings. Since their condition is unpredictable, minor body movements, life-like indications, or abnormal activities may get unnoticed if not continuously observed. Since there is uncertainty, treating such patients can be challenging.
To continuously monitor coma patient and keep a record of a monitoring system is proposed that specifically monitors the parameters that are important for a patient in a coma state, such as eye blinking, ECG, movement, and urine level. The system continuously monitors and keeps a record of patients' conditions through a database system that can be accessed by doctors, nurses, and patients' caretakers. The system will use a mobile application to notify the doctor or nurse if the patient's condition changes in any way.

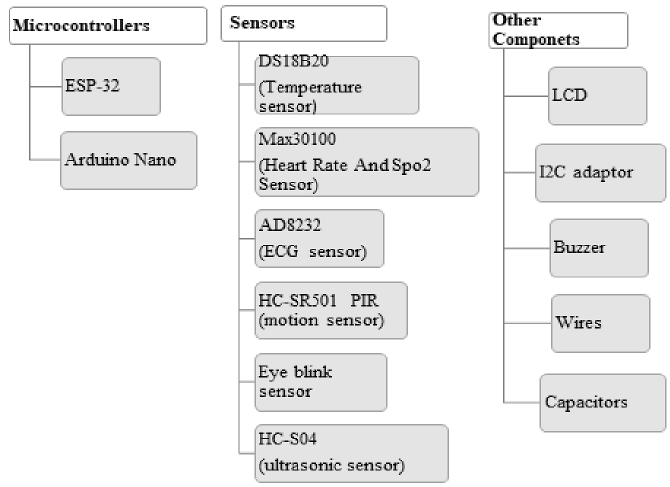

Figure 1. List of Components utilized in Smart Monitoring system

Table 1. Sensors & respective parameters

SENSORS	PARAMETERS
AD8232	ECG
HCSR04 (ultrasonic)	Urine Level
HCSR501 (PIR)	Movement
DS18B20	Temperature
MAX30100	Heart rate, SpO2
IR	Eye Blinking

LITERATURE REVIEW

This system's integrated approach attempts to create a suitable healthcare system that may be advantageous for both patients and physicians. The existing monitoring systems can detect only one or two parameters or may not have the facility of data base system, which makes this proposed system more reliable and better than the previous ones. It can detect as well as store all the data of respective patient. Some significant and related works have been focused in the literature.
The system's design includes a MATLAB-based pattern recognition algorithm, which processes each recorded image and sends an alert message to the attendant as well as display on LCD in case of movement (Dhillon, Kansal, & Dhillon, 2011). The system is divided into two portions: vital monitor and detection of physical changes. MEMS (micro-electromechanical system) used for movement detection. A serial communication is established between the controller and the doctor's computer, which displays any change in the patient (Koganti & Abhishek, 2013). The device is comprised of three parts: sensors, application and server. The sensors used in this system detect the heartbeat, eye blink and respiratory rate. All these sensors are interfaced with the Arduino Uno microcontroller. The software applications are Arduino-based, Android-based and a web service (Erlina et al., 2018).
The system uses 8081 microprocessor and interfaced heartbeat sensor, flex sensor and temperature sensor, which are attached to the patient's body. All of the values of parameters are uploaded in the cloud system and any changes in the parameters can be notified by an alert message (Peters, 2019). The Raspberry Pi microcomputer is interfaced with different sensors to monitor the patient's parameters like temperature, urine level, movement, eye blink, and blood pressure. The Raspberry Pi is then connected to the IoT platform Think speaks. It allows you to analyze, evaluate, and combine data and generate accuracy graphs to check the sensor's accuracy (Ramtirthkar et al., 2020).
The system [17] is divided in three sub units namely: detection unit, control unit and notification unit. ESP8266 Node MCU is used as the major control unit in this system. The detection unit consists of two sensors, a heart/pulse rate sensor and PIR sensor. The notification unit consists of a buzzer, Blynk app, and server, which allow the patient's attendant to know when the condition changes remotely (Anayo et al., 2021). This monitoring system is based on a Raspberry Pi microcomputer. The parameters measured are eye blinking, movement, urine level, EMG, temperature, humidity, and heartbeat. A peristaltic pump is also used for feeding the patient and a Pi camera for eye blinking. The data is transmitted through the sensors to the Raspberry Pi microcomputer, processed and then transmitted to the Google Cloud and the result displayed on mobile application The system also allows the measurement of temperature and humidity of the room in which the patient is held. Any change in

the patient's condition will generate an alert in the mobile application (Mahar et al., 2021).

MATERIALS AND METHODS

System Architecture

The architecture of this system comprised of two main sections

- Hardware architecture
- Software architecture

Hardware Architecture

The hardware utilized in this project is mostly composed of biological sensors and microcontrollers.

i. ESP32

System-on-chip microcontrollers from the ESP32 family provide integrated Wi-Fi and dual-mode Bluetooth and are reasonably priced and low-power. The ESP32 series, which also includes integrated filters, power amplifiers, low-noise receive amplifiers, RF baluns, and antenna switches, uses the Tensilica Xtensa LX6 microprocessor. The ESP32 platform supports applications for mobile, wearable electronics, and IoT. Its dual-mode Bluetooth and built-in Wi-Fi capabilities can be used to create a variety of network and (IoT) applications (ESP32 ESP-IDF Programming Guide, n.d.).

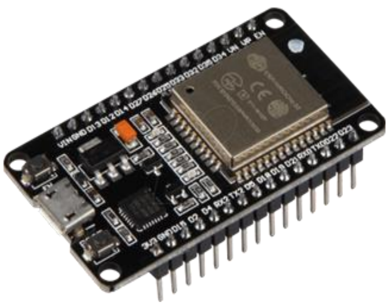

Figure 2. ESP 32 hardware (Introduction to ESP32, 2023)

Table 2. ESP Specifications	
Processor	Dual-core processor with clock speeds of up to 240 MHz
Peripheral interfaces	UART, I2C, SPI, PWM, ADC, DAC
Operating voltage	2.3V to 3.6V
Wireless connections	Wi-Fi (2.4 GHz up to 150 MBs/s) and Bluetooth (BLE)
Programming	Compatible with Arduino IDE and micro-Python

ii. Arduino Nano

Arduino Nano is one of the most popular and used of a microcontroller of the Arduino family often used by the beginners for electronics projects. It is a small breadboard-friendly microcontroller that uses ATmega328 as the controller chip. The Arduino Uno board contains analog and digital input-output pins that connect the board to other components. The Nano board is configured in a DIP30 style (Adnan Aqeel, 2023).

Figure 3. Arduino Nano (techZeero, 2023)

Table 2. Arduino nano Specifications	
Processor	Main Processor is ATmega328P running at up to 20 MHz
Memory	32KB flash, 2KB SRAM, 1KB EEPROM
Peripheral interface	USART, SPI, I2C, PWM
Operating voltage	5 volts
Programming	Arduino IDE

iii. MAX30100

The MAX30100 is a low-power, plug and play biometric sensor that's I2C-compatible. It is a heart rate and pulse oximetry monitor combined, which makes it the perfect option for any application. A pulse oximeter is comprised of a sensor, a processing unit and LEDs. These components measure the oxygen levels in your blood by looking at the amount of oxygenated hemoglobin in your tissues.

Figure 4. MAX30100 (Pelayo & Pelayo, 2023)

Table 3. Max 30100 Specification	
Range	-40°C to 80°C
Operating voltage	1.8V & 3.3V to 5V
Current Drainage	600µA (during measurements)
Sensitivity	R/IR of 0.5 equates to 100% SPO_2
Accuracy	96 – 99%

iv. PIR HC-SR501

A passive infrared (PIR) HC-SR501 can be used to track movement and occupancy using infrared emissions from a person or animal's body. In order to sound an alarm, the passive infrared detector depends on picking up infrared light from the human body. The temperature of the body's surface is 36–27 °C, and the bulk of its radiant energy exists in the 8–12 um wavelength range.

Figure 5. PIR Sensor (PIR Motion Sensor, 2014)

v. AD8232 ECG Sensor

The electrical activity of the human heart is measured using an AD8232 ECG sensor. An analogue reading produced by this procedure can be shown on a chart that resembles an ECG. Electrocardiograms may be quite noisy, and the AD8232 device can help reduce such noise. To help obtain a clear signal from the intervals, the ECG sensor's functioning functions similarly to an operational amplifier.

Figure 6. ECG module (AD8232 ECG Module, n.d.)

vi. Eye blink sensor

Eyes blink sensor work using infrared (IR) technology. IR sensors detect the presence of an object by measuring the amount of infrared radiation emitted, reflected, or transmitted by the object. In the case of an eye blink sensor, the IR sensor would be positioned near the eye and would detect changes in the amount of IR radiation being emitted by the eye as the eyelid moves during a blink. The sensor would then transmit this information to the processing unit which would then interpret the signal to detect the blink.

Figure 7. Eye blink Sensor with glasses (Robocraze, n.d.)

vii. Ultrasonic sensor

Ultrasonic sensors estimate the distance to an object or obstruction using high-frequency sound waves. They can also be used to detect the presence of objects and measure their size or speed. They are often used in robotics and automation, as well as in industrial, medical, and consumer applications. Ultrasonic sensors can be classified into two types: transmitters and receivers.

Figure 8. Ultrasonic Sensor (Ultrasonic Ranging Module HC-SR04, n.d.)

viii. DS18B20 Temperature Sensor

DS18B20 is a digital temperature sensor known for its accuracy and low power consumption. The sensor can easily be interfaced with microcontrollers. It uses the 1-wire protocol for serial communication with the microcontrollers. One of the important features of DS18B20 is that it can operate without an external power supply.

Figure 9. Temperature sensor (DS18B20 Temperature Sensor IC for Arduino Raspberry Pi, n.d.)

Software Architecture

The software part of the system consists of the programming software for the microcontrollers, firebase and the mobile application.

i. Arduino IDE

This prototype relies upon the Arduino IDE to program the microcontrollers used in the project. An open-source, free programming tool created by Arduino.cc named as Arduino IDE (Integrated Development Environment). This software is used to program the Arduino boards, allow sketching (working with hardware or manipulating data), and upload code to a range of modules. It consists of different libraries that provide extra functionality for sketching.

ii. Firebase

A database, sometimes referred to as an electronic database, is an accumulation of data or information that has been appropriately organised for convenient browsing and retrieval.

The cloud-based database used for this suggested solution is Firebase. The Firebase Real-time Database is a database that is hosted in the cloud and stores data in JSON. The data is synchronized in real-time for each connected client. All of our clients share a single Real-time Database instance and receive updates with the most recent data quickly when we develop cross-platform applications. The application has access to the most current value of the data as well as any modifications utilizing a single API via the Firebase database. Due to real-time synchronization, our customers may simply access their data from any device, including a web browser or a mobile phone.

iii. MIT App Inventor

The drag and drop visual programming tool MIT App Inventor is an online application development platform that enables to create fully functional Android mobile apps. The two main editors in the MIT App Inventor user interface are the design editor and the blocks editor. To arrange the components of the application's user interface, design editor is used, also known as the designer, which has a drag and drop interface (UI). With the use of color-coded blocks that fit together like jigsaw pieces to describe the programmed, app developers may graphically lay down the logic of their apps in the block editor.

Methodology

The developed system, being an IOT-based solution, demonstrates effortless connectivity capabilities by instantly establishing a connection to Wi-Fi upon activation. This allows users to seamlessly integrate the system into their existing network without any complicated setup procedures.

A network of specialized sensors is used in the proposed monitoring system to gather important data from the human body. To ensure accurate data collection, each sensor must be placed in its proper location on the body. For example, the eye blink sensor should be attached to the glasses to be worn, the ultrasonic sensor should be placed at the top of the urine bag to detect the level of urine, the PIR sensor bed is the suitable location as it should be on the front of the patient in order to detect the slightest movement, and the leads of the ECG should be placed on the chest as per the standard procedure.

All the sensors in this system are used for data acquisition, which is crucial for monitoring and analyzing the patient's health condition. The sensors continuously gather data on the corresponding physiological characteristics of the human body and convert it into electrical signals that can be processed and analyzed by the system. Following this, the next phase of data processing and analysis is placed under the control of a microcontroller, which is an essential component of the entire system.

After undergoing interpretation by the microcontroller, the processed data enters the respective database system, which is "Firebase" for this project. The database serves as an important pathway for connecting the hardware of the project with a mobile application. This bridge is essential for enabling the smooth flow of information and ensuring that users can get data from the sensors and microcontroller in an accessible and understandable format.

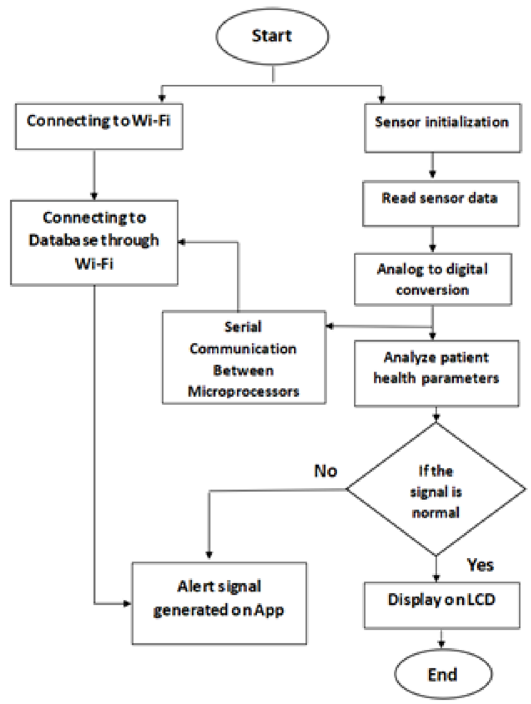

Figure 10. Process flow graph for continuous working of the smart monitoring system

Finally, data generated by the hardware is displayed on two platforms: an LCD and a mobile app that has been developed. The LCD provides a real-time display of the data for immediate viewing, while the mobile app allows users to access and analyze the data remotely. This dual-platform approach ensures that users have flexibility in monitoring and managing the generated data, whether they are on-site or off-site.

The system is programmed to detect any abnormality in the physiological vitals and generate an alert response on both the LCD and mobile application in the form of notification. This feature enables users to quickly respond to any critical situations, regardless of their location.

Experimental Setup

The setup of hardware, presented in Fig 12, is the final look of the proposed system, combining all the biological sensors along with the microcontrollers. The clear view of the working prototype has been shown. The setup placed in Biomedical Instrumentation Lab where compared with existing patient monitor and the 20 samples were taken during the testing and it was up to the mark. The setup performs the one cycle in 5 minutes' average.

RESULTS

Considering the project's desired outcomes, all the health parameters (i.e. body temperature, SPO2, heart rate, urine level, eye blink, movement and ECG) of the

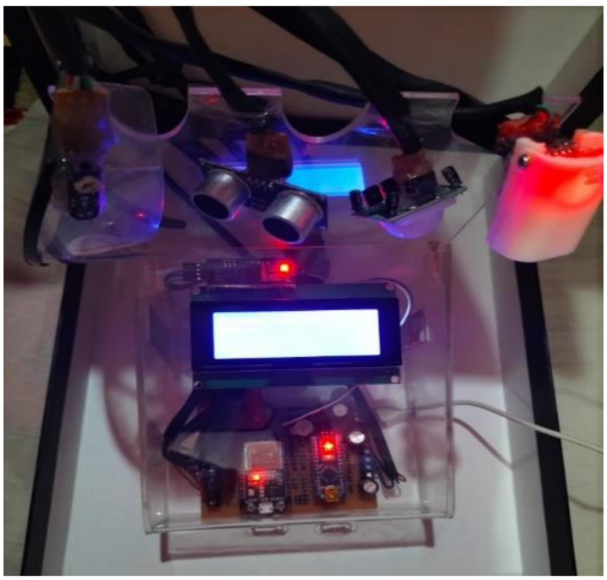

Figure 11. Hardware setup of the Smart monitoring system

subjects were shown in the application. The LCD is programmed to display specific parameters including body temperature, SPO2, heart rate, urine level of the subjects. The precise parameters are continually shown on the LCD until an interruption, (interrupt basically refers to any type of abnormality and eye blink or movement occurrence). The LCD display alert messages about the interruption and the buzzer activates when any abnormality, eye blink, or movement is detected. The application also provides alert notification for these parameters and informs the staff or family members about the changing in patient's condition.

The basic vitals of the smart monitoring system compared with the existing monitor present in Bioinstrumentation lab system by Nihon Kohden the outcomes were up to the mark and the sensors accuracy was nearly 97% +1.

Alert Generation

The LCD is responsible for the display of four parameters (SPO2, BPM, Temperature and urine level), but when it comes to alert display, the LCD also display alert for Eye blink and movement. These alerts might draw the attention of the medical staff, allowing

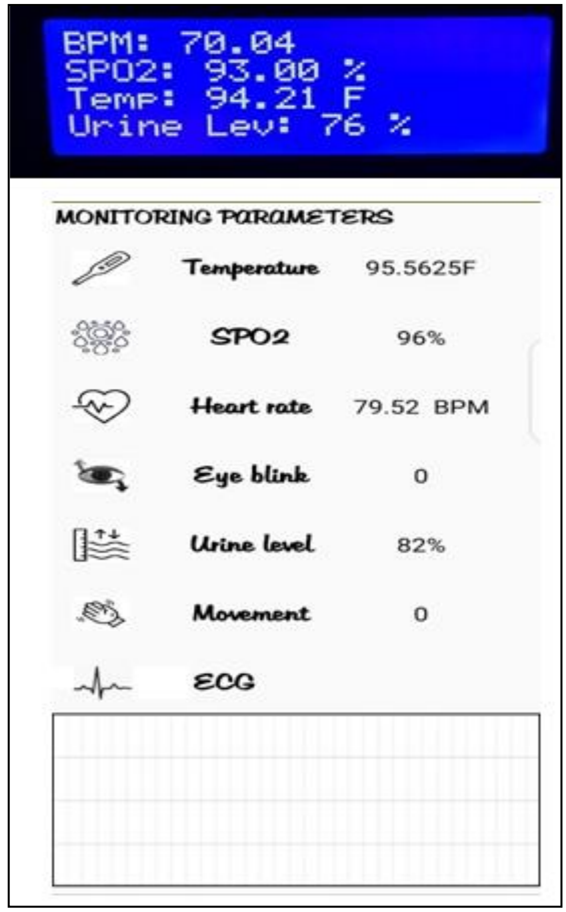

Figure 12. (Above) Readings of heartbeat (bpm), SpO2, temperature and urine level displayed on LCD screen and Mobile application screen showing (Below) all the parameters and ECG wave.

them to treat the abnormal condition of the coma patients. The alert generated by the prototype is audible as a buzzer and displayed on the LCD as shown in Fig 15.

The mobile phone application shows the values of all the sensors attached to the body along with the ECG wave. Notifications in the form of text are generated in case of any change in the parameters as shown in Fig 16.

DISCUSSION

This prototype is also capable of displaying the alert on the LCD in the event of any abnormality or certain interrupt condition, such as an eye blink or movement. The application is also designed to generate alert

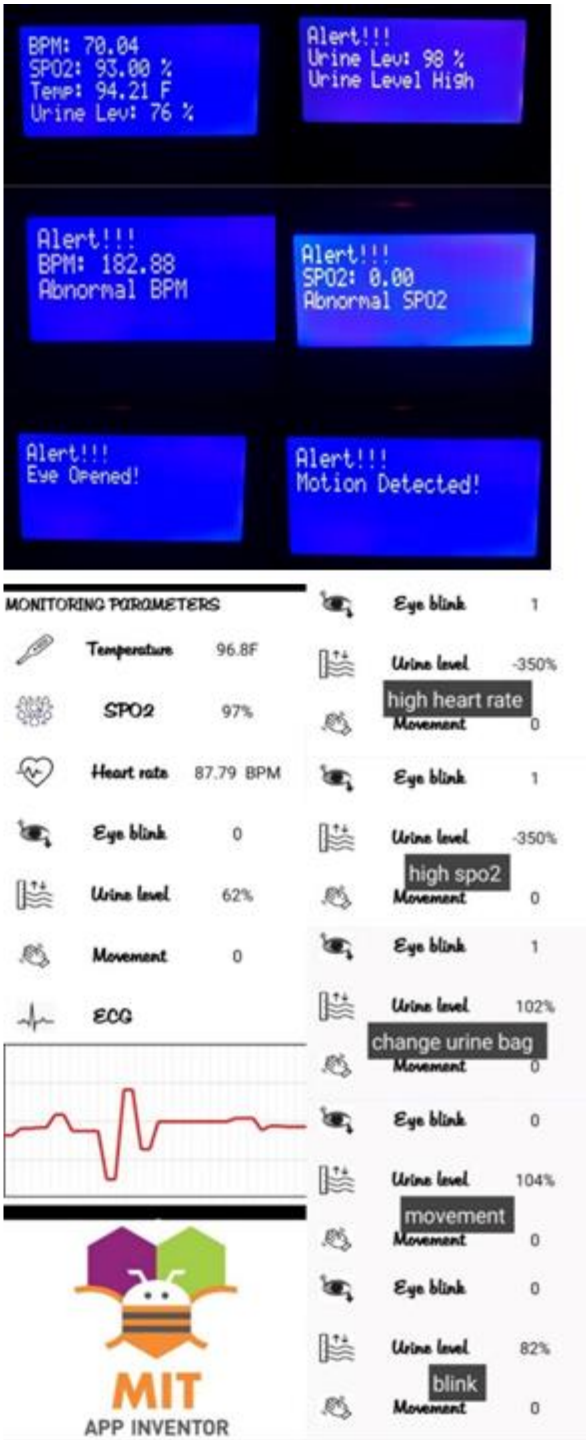

Figure 13. Alert generation system: Alert messages on LCD screen (Above) in case of abnormality & Alert notification on the mobile App (below) along with normal values of the parameters.

notifications based on the condition of the coma patient. These alerts on the LCD, via buzzer, and application notification play an important role in order to prevent any dangerous situation, as the patient is not conscious enough to communicate about his own condition to the doctors. The detailed monitoring can be done by the doctors even if the patient is shifted home, as the application can be accessed from anywhere with a Wi-Fi connection. In comparison to earlier monitoring systems this prototype has several additional sensors, which are responsible of detecting conditions that may be particularly important to monitor for patients who are in a state of coma. This prototype has a few restrictions and can be modified to be a better project for real-time monitoring. As the whole project is operated through the internet, any disturbance in the Wi-Fi signals can affect the performance of the prototype. A continuous and good-quality internet connection is therefore necessary for the functioning of the proposed monitoring system. The temperature sensor used in this prototype needs at least 60 seconds to detect the body temperature accurately, which can affect the efficiency of the whole project.

CONCLUSION

The monitoring system for comatose patients has been found to be effective at measuring the patient's parameters and sending alerts in the event of abnormalities. The use of many sensors makes this prototype different from the existing systems. The detection of any change in the patient’s parameters and the generation of alert notifications are the main purposes of this prototype. Due to the use of a wireless network, it allows real-time monitoring of the patients even in remote areas through the mobile application and Firebase as an IoT platform. The system is developed using various cost-effective components. The mobile phone app provides real-time monitoring and a notification alert when there’s a change in the parameters. Apart from the mobile app, the values of all these parameters are shown on the LCD screen, and abnormalities are detected by the buzzer sound. Health care practioners and family members can keep the record of the coma patient remotely either they got any problem or need any kind of medical assistance.

LIMITATIONS AND FUTURE WORK

As technology develops every single day, there is always room for innovation and progress to make any form of prototype more efficient and useful for humanity. According to the findings and analysis from testing this prototype, a few elements were taken into account that may be changed to increase the prototype's efficiency by putting in further effort in the form of innovative technology. Those considerations for future enhancement are listed below:

As slight changes in health parameters can lead to dangerous situations for the patient in a coma state, the

accuracy of the detection and measurement modules plays the most prominent role in making the system ideal for the particular task of monitoring.
Another modification that can further improve the usability of the prototype is adding more parameters to be detected. Additional sensors can be incorporated to detect more parameters in order to maintain the patient's health by monitoring all those parameters. For instance, this prototype lacks any sensors that are set up to measure the patient's blood pressure, despite the fact that this is a vital measure of the patient's health. Integrating a sensor of this sort would assist in this system development. An efficient database cloud may be created to retain patient information and changing medical situations that occurred while using the monitoring system, allowing for the preservation of records for current or former patients.

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