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An IoT Enabled Cost Effective Smart Healthcare for Real-Time COVID-19 Patient Early Identification and Monitoring System Using Smartphone

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Abstract

The SARS-CoV-2 virus causes COVID-19, a highly contagious disease. Meetings between COVID-19 patients, their families, and medical professionals are no longer safe. To meet their patients, doctors and patients' families must take extreme precautions. Even with these stringent safety precautions, there is a chance that he or she will be affected by COVID-19. In this context, remote patient monitoring via IoT devices can be a highly effective system for today's healthcare system with no safety concerns. This paper describes an IoT-based system for remote monitoring of COVID-19 patients that uses measured values of the patient's heart rate, body temperature, and oxygen saturation, which are the most critical measures required for critical care. This device can monitor the observed body temperature, heart rate, and oxygen saturation level in real time and can be easily synchronized with a ThingSpeak IoT cloud platform channel for instant access through a smartphone. When the sensor value exceeds the system's safe threshold, the system will send an email alert to the system user. Some people may notice a decrease in oxygen saturation without any symptoms or respiratory problems. This system can be very useful for early COVID-19 identification in this case. The proposed IoT-based technique is based on an Arduino Uno system and has been tested and validated by a large number of human test participants. As an example, five sample results are shown in this paper. The system yielded promising results. When compared to other commercially available devices, the system's results were found to be accurate, with a maximum error rate of less than 5%, which is quite acceptable. The system's data can be saved in the ThingSpeak cloud server for further analysis. This system requires a unique email and password verification to maintain system security and user data privacy. This patient monitoring system has grown in popularity during this COVID-19 pandemic due to its uniqueness and diverse medical applications. Many people's lives are impacted every day when illnesses are not identified in a timely and accurate manner, denying us the opportunity to provide medical care. To deal with such scenarios, this system will help to monitor a COVID-19 patient's specific parameters, predict the patient's status on a regular basis, and send an email alert to the system user if something abnormal occurs. As a result, this IoT-based smart healthcare solution could help save lives during the current COVID-19 pandemic. This technology is easy to use and reduces the need for human intervention.

Keywords—Patient monitoring system, Internet of things, Sensors, ESP8266, COVID-19, IoT, Health monitoring, Oxygen saturation, Arduino UNO, ThingSpeak, Cloud platform.

Introduction

The COVID-19 pandemic is one of the most critical global health concerns affecting healthcare organizations today. It has already resulted in a significant loss of human life, including that of healthcare workers. According to global news, the total number of people worldwide proved to have been infected with coronavirus is more than 520.4 million as of May 14, 2022, while the total number of coronavirus mortalities is more than 6.29 million, indicating that COVID-19 instances are increasing internationally [1]. Vaccine distribution has helped to reduce the death rate, but slow vaccine production has already cost many lives. Because of the virus's high mutation rate, new variants are emerging and vaccines are facing challenges. As a result, as seen with the recent Omicron variants, these new variants put additional strain on the healthcare system [2]. More deaths are also being caused by a lack of ICUs (intensive care units) and late identification. This virus is not only disrupting daily life but also the global economy. Due to the strict lockdown and disruption of normal business activities around the world, it has reduced the global GDP of developed and developing countries. As a result, recovering from this is a major concern for the countries, and in order to do so, the virus's spread must be reduced to a lower level. Vaccination and proper health monitoring can assist in overcoming this. Some symptoms indicate that the patient has COVID-19. COVID-19 symptoms include fever or chills, exhaustion, muscular or body pains, shortness of breath, decreased oxygen saturation, dry cough, diarrhea, vomiting, sore throat, headache, congestion or runny nose, loss of taste and smell, bodily pain, and irregular pulse rate [3], [4]. High body temperature, low oxygen saturation, and an irregular pulse rate are all considered dangerous symptoms. As a result, COVID-19 patients' health status, particularly their body temperature, heart rate, and oxygen saturation, must be monitored. Early detection of these symptoms can help to slow the virus's spread and save many lives. In this case, IoT-based smart healthcare can be useful for tracking these symptoms.

As information technology has improved, the concept of smart healthcare has grown in popularity. Smart healthcare makes use of a new generation of information technology, such as the internet of things (IoT), big data, cloud computing, and artificial intelligence (AI), to completely replace the existing medical system, making healthcare more efficient, easy, and customized. The Internet of Things (IoT) was employed in this research to provide smart healthcare to Covid-19 patients. The Internet of Things (IoT) is a networked system of interconnected computing devices with unique IDs and the capacity to transfer data without needing human-to-human or human-to-computer communication [5], [6]. Because Covid-19 is a highly infectious illness, every nation confronts challenges in delivering effective treatment to its patients due to a huge rise in active COVID-19 cases during the second wave. There is also a safety concern for healthcare personnel and patients' family. As a result, remote monitoring for Covid-19 patients via IoT devices is critical for saving valuable human life during this Covid-19 period. The three most critical indicators for covid-19 patients are pulse rate, body temperature, and oxygen saturation level. The pulse rate, or the number of times the heart beats per minute, is a measurement of the heart rate. The arteries expand and constrict with the flow of blood as the heart pumps blood through them. Taking a pulse not only measures the heart rate but may also reveal the heart rhythm and pulse strength. A healthy adult's pulse rate varies between 60 and 100 beats per minute. Exercise, sickness, injury, and emotions can cause the pulse rate to rise and fall. On average, females aged 12 and up have quicker heart rates than males [7]. Athletes that perform a lot of cardiovascular fitness, such as runners, may have heart rates approaching 40 beats per minute and have no concerns [7]. However, the pulse rate of COVID-19 patients is abnormal or irregular, necessitating the assistance of an emergency medical assistant. Body temperature is also an essential consideration for covid-19 patients. A person's typical body temperature changes based on gender, time of day, recent exercise, food, fluid consumption, and for women, menstrual cycle stage. A healthy adult's body temperature can range between 97°F (36.1°C) to 99°F (37.2°C) [8]. Fever (high temperature) or hypothermia can cause abnormal body temperature (low temperature) [7]. A fever of more than 100.4°F (38°C) is usually caused by an infection or disease [8]. A dip in body temperature below 95 degrees Fahrenheit is defined as hypothermia [7]. Fever is a frequent sign of various disorders, including COVID-19; thus, it is important to take the body temperature regularly. In COVID-19 patients, oxygen saturation is also crucial. The human body's typical SpO2 (Saturation of Peripheral Oxygen) varies from 95 to 100%. A COVID-19 patient requires emergency medical attention if their SpO2 (oxygen saturation) level is less than 95%. A COVID-19 patient may die if his or her oxygen saturation level is extremely low. So, it is critical to monitor all the three early and crucial signs such as fever, cough, heart rate, and SpO2 to manage COVID-19.

Currently, a variety of commercial devices are being used to measure body temperature, heart rate, and SpO2. In most countries, a fingertip pulse oximeter for measuring SpO2 and pulse rate is commercially available [9]. This oximeter is compact and cheap compared to other devices. A wrist-worn pulse oximeter, which can monitor SpO2 and heart rate, is widely accessible. This gadget, like the previous ones, lacks body temperature measuring capabilities. The wrist-worn pulse oximeter is pricey, costing 128 USD [10]. The Berry hand-held pulse oximeter, which can monitor SpO2 and heart rate, is also commercially available, however, it costs 18500 BDT, equivalent to 207$ [11]. It has unique features such as USB connectivity for remote data storage in computers or smartphones. There are presently analog and digital thermometers on the market, however, the majority of them are pricey [12]. The gadgets listed here are not IoT-based. Some of them display values, but obtaining measurements from various equipment is time-consuming and also the products are not cheap. As a result, it is difficult for a doctor to collect updates from all patients at once. And, at this time of the pandemic, there is a need for urgent remote monitoring of COVID-19 patients with severe symptoms. Quarantined and suspected Patients can now receive COVID-19 therapy from home using their smartphones because of advances in technology [13]. This technique assists individuals who have a fever, poor oxygen saturation, or a pulse rate that is rising or dropping. Furthermore, for the aged person, it becomes increasingly important for them to get regular medical health examinations as this COVID-19 has a high fatality among the aged people. Because it might be time-consuming and difficult for most aged people to acquire frequent health checkup visits, IoT-based arrangements for remote routine health exams can be advantageous to aged individuals [14].

Some significant contributions have been made in the realm of medical science by utilizing IoT to track patient health conditions. Xundong et al. proposed an IoT-enabled real-time health monitoring system based on deep learning. Wearable medical devices are used to measure vital signs, and various deep-learning algorithms are used to extract relevant information [15]. Shuishen et al. suggested fog-aided computationally efficient wearable sensor networks (FCE-WSN) in IoT-enabled health monitoring systems for athletic activities [16]. The wearable device was examined for continuous real-time monitoring of heart rate, breathing frequency, and movement cadence during physical exercise. Furthermore, the sensor data is transferred to the IoT-connection system Ethernet module, and the Authorized Individual accesses the data through the internet to follow the health of the athletes [16]. Banerjee et al. [17] presented a noninvasive approach for detecting pulse rate. The suggested system utilized plethysmography and digitally showed the result, making it a real-time monitoring instrument. In comparison to other intrusive treatments, the approach has proven to be as trustworthy for the patient. Trivedi et al. [18] proposed an Arduino-based health parameter monitoring system controlled by a smartphone. Sensors are used in the system to measure these characteristics non-invasively. These sensors are linked to the Arduino Uno microcontroller board, which communicates data wirelessly over Bluetooth to the user's Android-enabled smartphone. The Bluetooth gadget employed a module that did not cover a large region. The research examines the application of IoT systems for patient monitoring in smart cities so that ambulances and other aid can reach patients' locations [19]. Another research looks at the future role of IoT in human health monitoring, with an emphasis on illness management, patient satisfaction, effective treatment, and the function of 5G in connectivity [20]. In [21], a wearable health monitoring system for COVID-19 patients with a real-time tracking function for position tracking with the inbuilt GPS was presented. The entire system is linked to an Android UI through API to track the recovery and health status of the recovered patient. Otoom M. et al. [22] designed an IoT system for identifying possible COVID-19 patients using eight different learning algorithms that assist to distinguish the cold symptom from COVID-19 symptoms. A paper from Kondaka's research team discusses the significance of machine learning in reviewing and storing data on the cloud for accurate illness prediction. Deep learning algorithms may be used to eliminate flaws and faults in IoT smart health systems, such as data transfer ratios from smart medical devices to servers, storage correctness, and connectivity efficiency [23].

In this context, our work focuses on developing an IoT-based smart health monitoring system for COVID-19 patients based on data from the patient's body temperature, pulse rate, and oxygen saturation level. Through a ThingSpeak channel link [24], the device can display measured oxygen saturation levels, heart rate, and body temperature, allowing the patient to request medical care even if the specialist is physically unavailable. To treat a COVID-19 patient, a doctor must know the patient's oxygen saturation level, heart rate, and body temperature. Patients can use our proposed way to examine their health status on their smartphones and alert doctors about any health problems. If a patient's oxygen saturation, pulse rate, or body temperature are abnormal, the channel's continuous monitoring can promptly alarm. This system's ThingSpeak IoT cloud platform can run MATLAB code, do online analysis and data processing with live data, and view automated visualizations. As a result, the suggested method could be extremely beneficial to healthcare professionals treating COVID-19 patients.

The rest of the work is structured as follows. The prototype's major hardware components have been thoroughly covered in the section "Familiarization with Materials and IoT Cloud Platform". The "Methodology" section displays the proposed IoT system's design methodology and implementation details. In the section "Experimental Result Analysis and Comparison," the experimental results are explained, evaluated, and compared to some recent publications. The "Conclusion" part of the study finishes with some future work.

Familiarization with Materials and IoT Cloud Platform

The patient monitoring system is made up of two parts: hardware and the ThingSpeak Channel. Both parts are essential to the system. This patient-monitoring device can monitor body temperature, oxygen saturation, and pulse rate. This multifunctional system necessitates the implementation of numerous components. Implementation is accomplished by carrying out the actions outlined in a work plan. The components necessary to run this system are briefly outlined below. Table 1 contains a list of the needed hardware components, their quantities, and the prices of the items. The total cost of the hardware components for this system is 1336 Bangladeshi Taka (BDT), which is comparable to 15.22 US dollars [25]–[29].

Table 1: Lists of the required hardware components with cost calculation

Item description	Unit price (BDT)	Quantity	Total price (BDT)
Arduino Uno	400	1	400
MAX30100 Finger Oximeter Heart Rate Module	380	1	380
LM35 Precision Centigrade Temperature Sensors	50	1	50
Node MCU ESP8266	299	1	299
Power Bank	150	1	150
Wire set	57	1	57
		Total	1336

This necessitates the use of the hardware and materials listed below. The following is a list of hardware and materials: 1. Arduino Uno 2. MAX30100. 3. Node MCU ESP8266 4. Using the ThingSpeak Website Channel as an IoT cloud platform. 5. A wire set 6. Power bank as Node MCU power supply.

1. Arduino Uno

Commercially available Arduino boards include the Arduino Uno, Arduino Due, Arduino Mega, Arduino Leonardo, Arduino Yún Rev2, Arduino Zero, and Arduino Micro [30]. The Arduino Uno contains 20 I/O pins, including 14 digital I/O pins (six of which may be used as PWM outputs), six analog I/O pins, a 16 MHz ceramic resonator, a USB connection, a power port, an ICSP header, and a reset button [31]. There are 54 digital I/O pins, 12 analog input pins, and two analog output pins on the Arduino Due. The Arduino Mega features 54 digital I/O pins, 16 analog inputs, and 0 output pins. The Arduino Leonardo features 20 digital I/O pins, 12 analog inputs, and 0 analog output pins. The Arduino Yn Rev2 is a Linux-based device with 20 digital I/O pins and 12 analog I/O pins that supports sophisticated network connections and applications. The Arduino Zero is a powerful 32-bit expansion of the UNO architecture, with 20 digital I/O pins, 6 analog inputs, and one analog output pin. The Arduino Micro is powered by an ATmega32u4 CPU and has 20 digital I/O pins, 12 analog inputs, and zero

Figure 1: Microcontroller Arduino UNO

analog output pins. We used the Arduino Uno to create the system since the pin arrangement of this module meets the criteria of our system and serves as the system's main controller. It is a well-known open-source 8-bit RISC (Reduced Instruction Set Computer) based microcontroller board based on the ATmega328p [32]. It includes 32 KB of ISP Flash memory with read-while-write capabilities, 2 KB of SRAM, 1 KB of EEPROM, and a built-in 10-bit SAR (Successive Approximation Register) ADC [33], [34]. The Arduino IDE [35] is used to program this microcontroller. It is critical in this system and serves as an interface between the sensors and the other IoT devices. Figure 1 depicts the physical picture of the Arduino Uno R3 microcontroller device.

2. Pulse Oximeter and Heart-Rate Sensor IC: MAX30100

The MAX30100 is a sensor system that combines pulse oximetry with a heart-rate monitor. Figure 2 depicts the SpO2 Pulse Sensor prototype (MAX30100). Saturation of peripheral oxygen (SpO2) is a blood vessel oxygen saturation calculation that relates to the quantity of oxygenated hemoglobin in the blood. Ordinary SpO2 levels in the human body vary from 90 to 100 percent. A MAX30100 pulse oximeter was appropriate for this setup. It is a combined

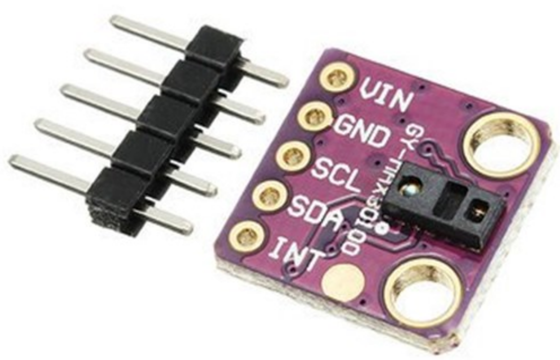


Figure 2: Pulse Oximeter and Heart-Rate Sensor IC

pulse oximeter and heart rate sensor combination that offers accurate results. It detects pulse oximetry and heart rate signals by combining two LEDs, a photodetector, improved optics, and low-noise analog signal processing [36]. The MAX30100 is supplied by 1.8V and 3.3V power supplies and may be turned down by software with little standby current, allowing the power supply to be connected at all times. [36] Its ultra-low-power mode extends the battery life of wearable gadgets. This device's advanced functionality increases measuring performance. Its high SNR enables robust motion artifact resiliency, integrated ambient light cancellation, high sample rate capacity, and quick data output.

3. LM35: Precision Centigrade Temperature Sensor

The LM35 sensor is a precision integrated-circuit temperature device having a linearly proportional output voltage to the temperature in degrees Celsius. It outperforms linear temperature sensors calibrated in Kelvin because the user does not have to remove a huge constant voltage from the output to get appropriate Centigrade scaling. It does not require any additional calibration or trimming to achieve average accuracies of ±¼°C at room temperature and ±¾°C throughout a temperature range of −55°C to 150°C. Trimming and calibration at the wafer level ensure lower costs. The LM35 device's low output impedance, linear output, and perfect intrinsic calibration make connecting to readout or control circuitry a breeze. The gadget works with either a single power supply or plus and minus supplies. Because the LM35 gadget only uses 60 μA from the power source, it has a very low self-heating temperature of less than 0.1°C in still air. The LM35 gadget can work in temperatures ranging from −55°C to 150°C [37]. Figure 3 depicts an LM35 prototype.

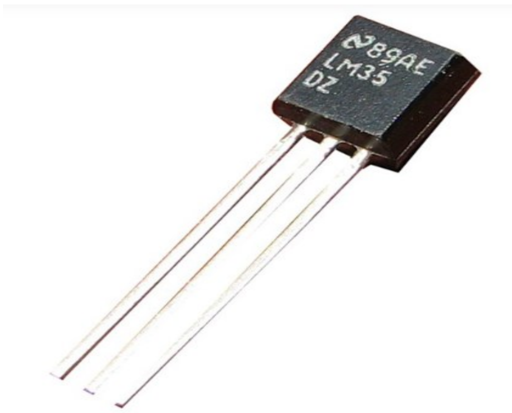


Figure 3: LM 35 Precision Centigrade Temperature Sensor

4. ESP 8266 Node MCU: Integrated Wi-Fi Microcontroller Unit (MCU)

The ESP 8266 Node MCU is a low-cost, fully integrated Wi-Fi MCU for IoT applications. As a result, this device was chosen for this research project. The ESP8266 microcontroller incorporates a Tensilica 32-bit RISC processor, which consumes very little power and has the highest clock speed of 160 MHz [38]. Approximately 80% of the processing power is accessible for user application programming and development, thanks to the Real-Time Operating System (RTOS) and Wi-Fi stack. The ESP8266 Node MCU can be powered by a 3.3 V operational voltage power source [38]. Because it incorporates a 32-bit Tensilica CPU, standard digital peripheral interfaces, RF balun, antenna switches, low noise receive amplifier, power amplifier, filters, and power management modules, this device is compact. They are all bundled in one small package. Because of its large working temperature range, it can perform reliably in industrial situations. The chip provides reliability, compactness, and resilience thanks to fully integrated on-chip functionality and a low external discrete component count. The ESP8266 Node MCU, designed for mobile devices, wearable electronics, and IoT applications, achieves low power consumption with the use of various patented technologies. The power-saving architecture has three phases of operation: active mode, sleep mode, and deep sleep mode. This permits battery-powered systems to run for extended periods [38]. The detected body temperature, pulse rate, and oxygen saturation are sent to the server via the node MCU wireless module. This component was chosen because it connects the server IP address to the node MCU, allowing the measured value to be obtained via a smartphone. It is specifically intended for IoT-based applications, and it is an essential component of our system. Figure 4 depicts the Node MCU ESP8266 microcontroller prototype.

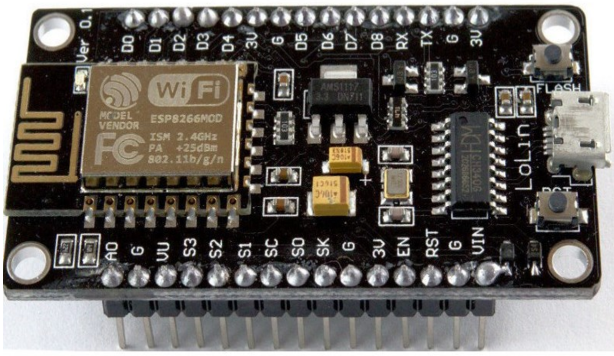


Figure 4: Node MCU ESP8266 (Wi-Fi Module)

5. ThingSpeak IoT Cloud Platform

ThingSpeak is an open-source program that enables users to communicate with internet-connected devices. Offering an API to both devices and social network websites, simplifies data access, retrieval, and logging. ThingSpeak can receive data from internet-connected devices, make rapid visualizations of live data, and deliver warnings. Figure 5 shows the interface of the ThingSpeak website. [24]

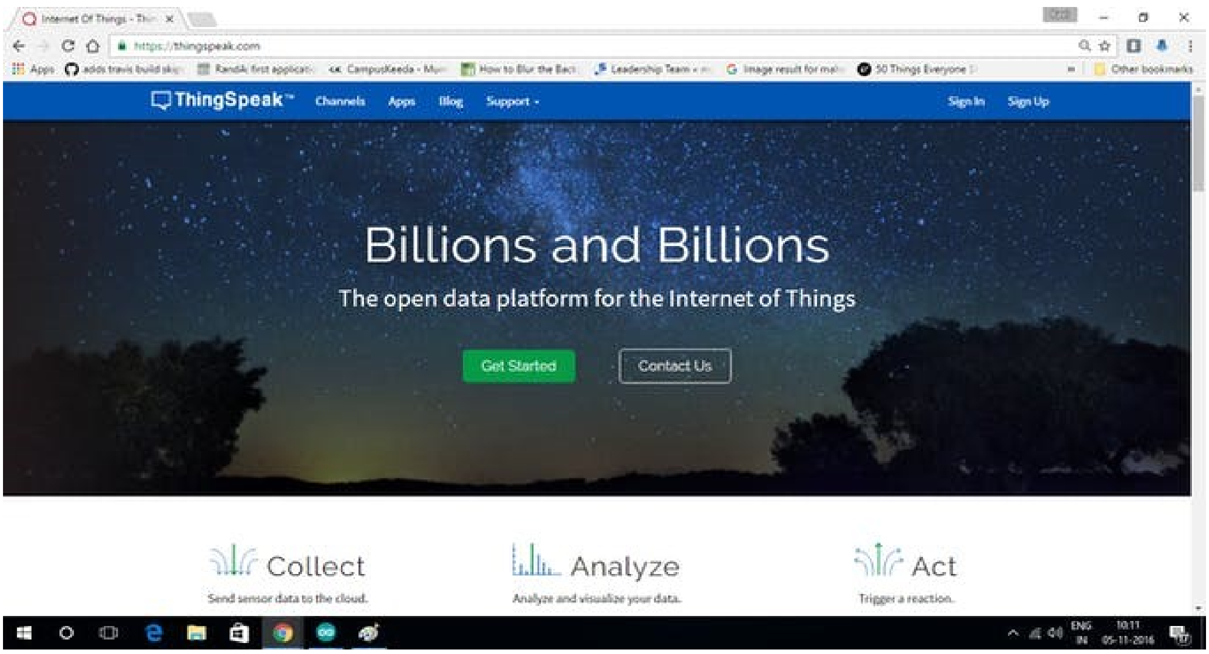


Figure 5: ThingSpeak IoT Analytics Platform.

Methodology

The sensor MAX30100 is the system's main piece of equipment. It detects pulse and pulse-rate signals by combining two LEDs, a photodetector, improved optics, and low-noise analog signal processing. The photodetector measures the amount of light transmitted at each wavelength. The blood oxygen content is estimated using the discrepancies in the readings. Light is transmitted through the transmitting material using one of two processes. The reflectance approach was utilized in this gadget. The LED and photodetector are arranged on the same side, adjacent to each other, in the reflectance approach. Because of the finger, there will be some fixed light reflection back to the sensor in this manner. As previously stated, the sensor is made up of two transmitting LEDs: a red LED with a wavelength of around 650 nm (Nano-meter) and an infrared LED with a wavelength of 950 nm. The absorption coefficient of Oxygenated hemoglobin to different light wavelengths is depicted in Figure 6. Oxygenated hemoglobin (RED line) absorbs higher infrared light than red light in this case. Furthermore, De-Oxygenated hemoglobin (blue line) absorbs higher red light than infrared light. The oxygen level of the blood can be estimated simply by measuring how much red light (R) is absorbed vs infrared (IR) light. The ratio of red light absorbed versus infrared light (R/IR) absorbed changes depending on the amount of Oxygenated hemoglobin or De-Oxygenated hemoglobin present. This ratio can then be converted into a SpO2 number using a look-up table based on the Beer-Lambert law. The majority of manufacturers maintain their look-up table. Typically, a R/IR ratio of 0.5 corresponds to around 100 percent SpO2, a ratio of 1.0 corresponds to approximately 82 percent SpO2, and a ratio of 2.0 corresponds to 0 percent SpO2.

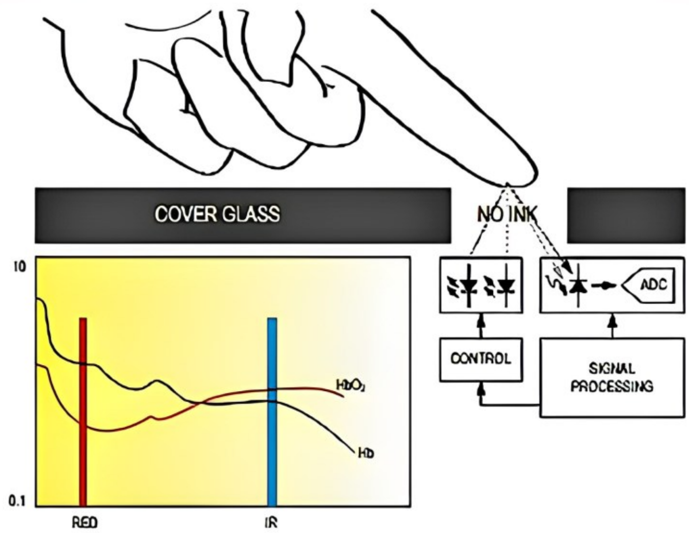


Figure 6: System Block Diagram of MAX-30100 Sensor [36]

In the case of pulse rate sensing, just infrared light is required. As a result of having more blood, there is a rise in oxygenated blood when the heart pumps it. The amount of oxygenated blood reduces when the heart relaxes. The pulse rate is calculated by measuring the time between the rise and drop of oxygenated blood. The findings show that oxygenated blood absorbs higher infrared light and transmits more red light, whereas deoxygenated blood absorbs higher red light and transmits more infrared light. In this method, the MAX-30100 computes the oxygen saturation (SpO2) and pulse rate and communicates it to the Arduino Uno. The LM35 temperature sensor delivers the value of the body temperature to the Arduino Uno. Sensors acquire data from Covid-19 patients in this manner. The analog data is then converted into digital data by the Arduino UNO. Both the Arduino UNO and the Node MCU ESP8266 are written in C++ such that the Arduino delivers the measured data to the Wi-Fi module (Node MCU 8266) and then one mobile hotspot is formed with a defined name and password, allowing the Node MCU to deliver live data to the ThingSpeak channel. As a result, anybody with the necessary link can monitor the health data of covid-19 patients monitoring. Figure 7 shows the whole process with a flowchart.

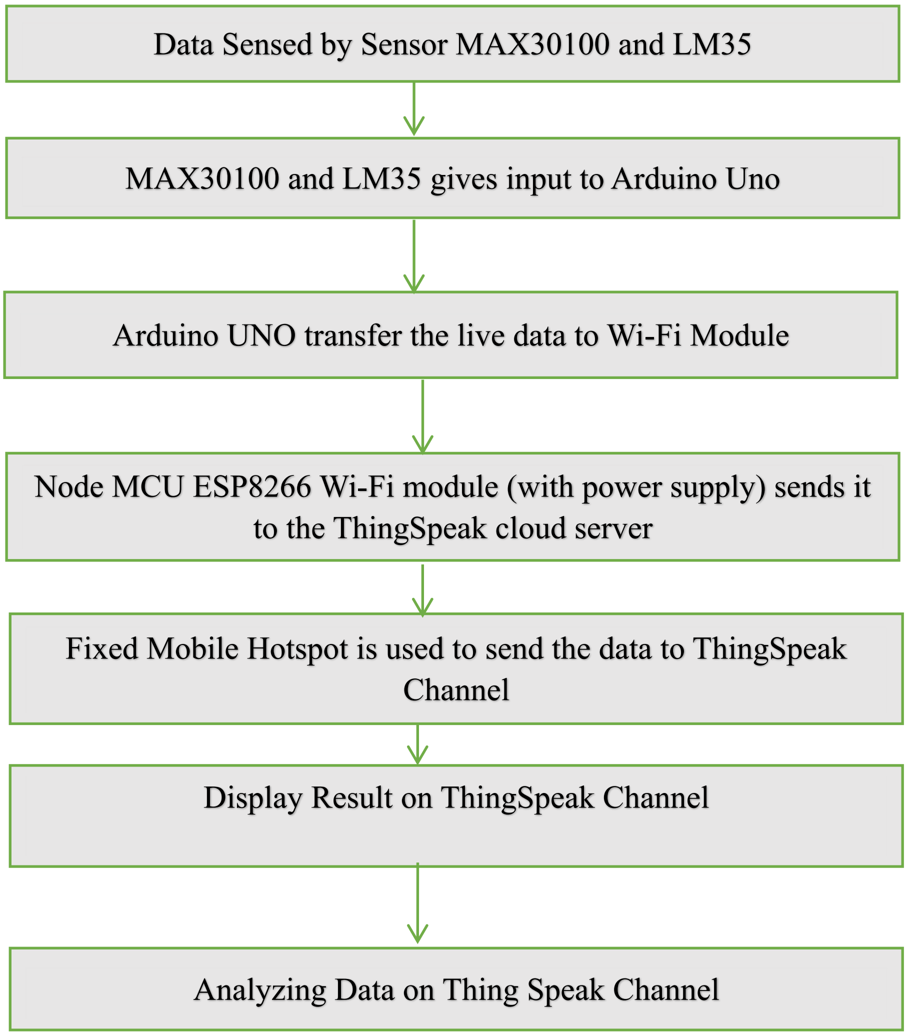


Figure 7: Flowchart of the proposed system.

The system block diagram in Figure 8 demonstrates that when the system's power is turned on, the sensor begins to take values. The system uses three types of sensors to measure the Covid-19 patient's SpO2, pulse rate, and body temperature. Doctors and patient families can continuously watch the Covid-19 patient via the ThingSpeak channel without any safety measures.

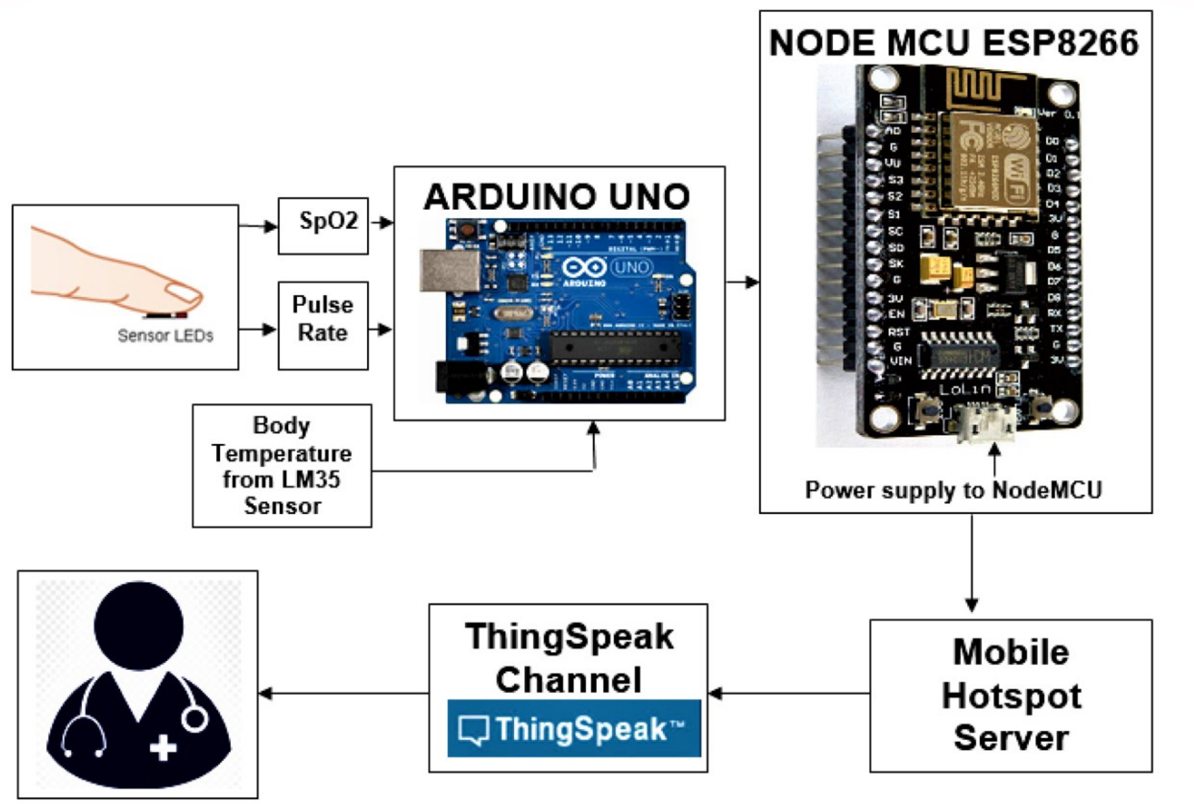


Figure 8: Block Diagram of Proposed Covid-19 Patient Monitoring System

Experimental Results and Comparative Analyses

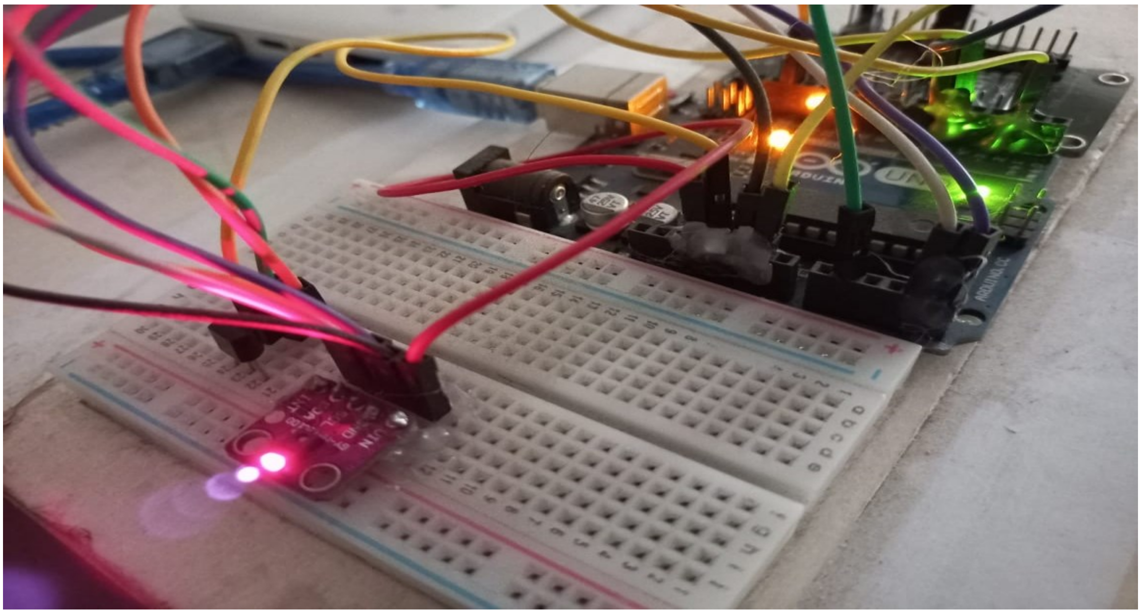
Following a thorough examination of the system, it was found that it functioned well. This signifies that the project's system design and implementation procedures were right, and hence the user's data were accurately measured. The entire system is divided into two major components. Users can acquire measured values of their vital signs using this system via a ThingSpeak Channel link. The data of five separate users are assigned in Table 2.

Table 2: SpO2, pulse rate, and body temperature of 5 different users from this system.

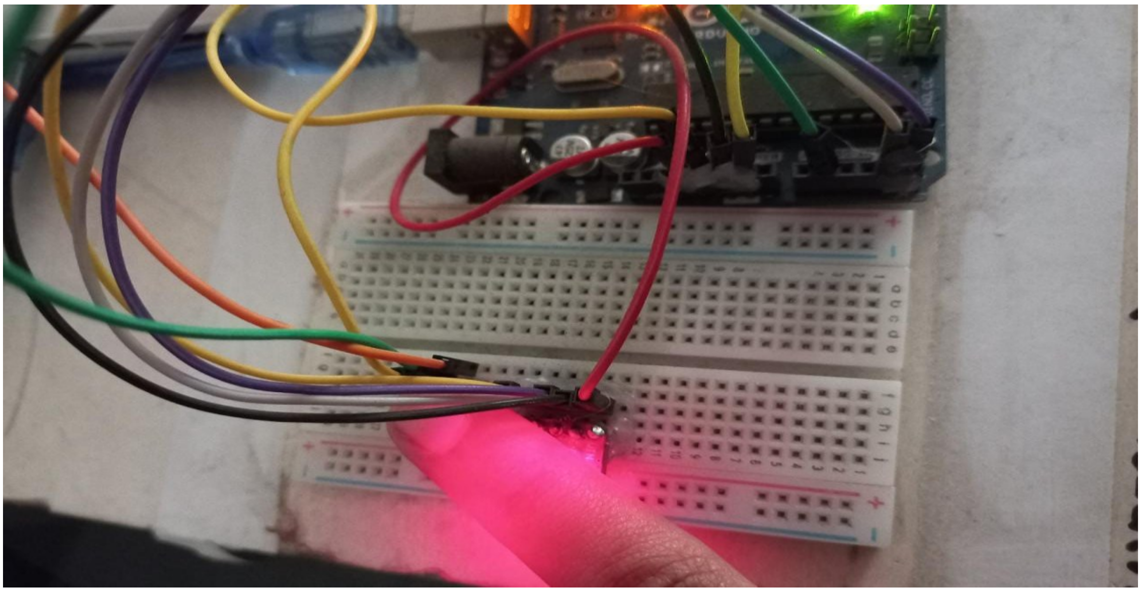
Samples	Body Temperature (◦C)	SpO2 (%)	Heart Rate (bpm)
Person 01	36	97	97
Person 02	36	99	75
Person 03	40	95	87
Person 04	37	97	75
Person 05	36	98	98

The system was tested on a real human test subject. It displays the user's recorded body temperature, SpO2, and pulse rate as a graph with time-based data collecting. This system sends data to a smartphone, which is one of its most important components. As a result, this method is user-friendly and convenient.

This system prototype is straightforward to use. Because it is a lightweight prototype, it can be simply transferred from one site to another. Figure 9 depicts the suggested system's prototype.



(a)



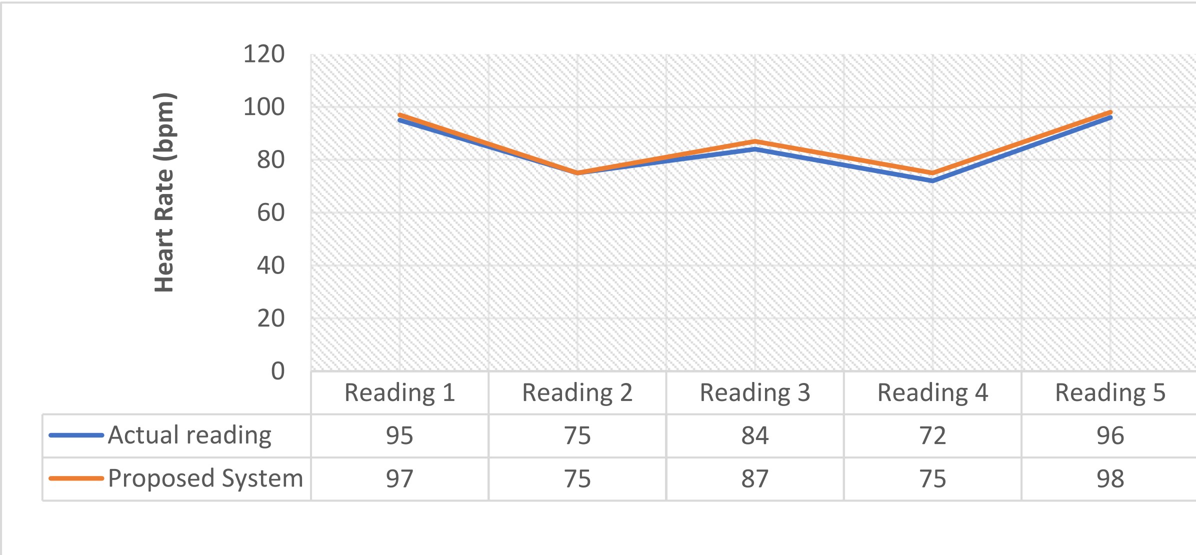
(b)

Figure 9: (a) System prototype (b) A user is checking his health condition with this system.

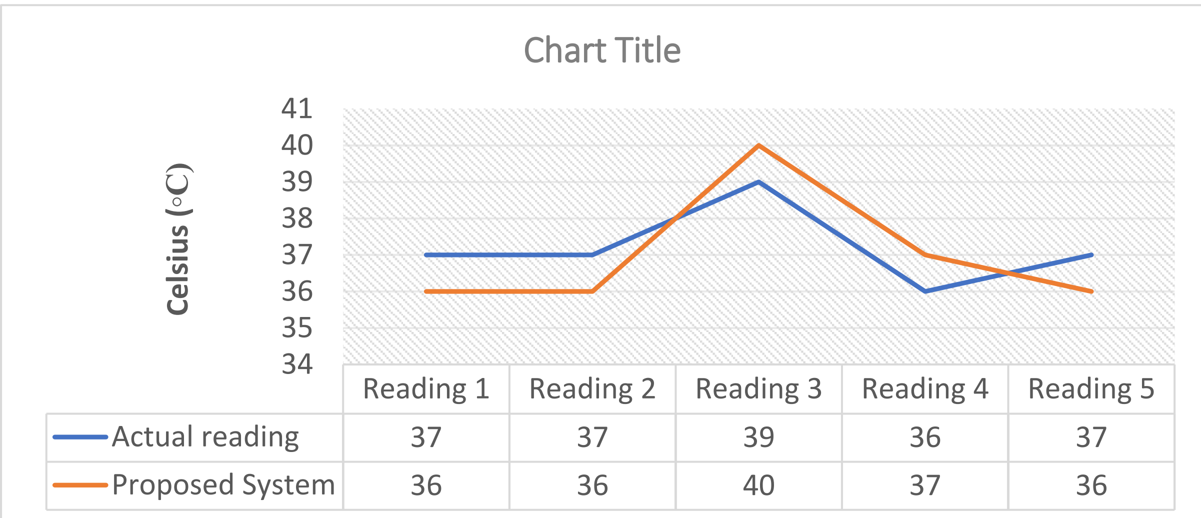
To assess the accuracy of the proposed system, the results were compared to commercial discrete devices, as shown in Figure 10. Figure 10(a)-(c) shows that there are minor differences between the commercial device reading and the proposed system reading. And it is negligible. Discrepancies can occur due to patient movement, sensor displacement during measurement, and sometimes environmental noises that have a minor impact on the measurement.

Figure 11(a)–(c) shows the error rate of the designed method for SpO2, heart rate, and body temperature. The greatest error rates for the three examples are 4.28 percent, 0.81 percent, and 3.07 percent, respectively, while the lowest are 1.49 percent, 0.41 percent, and 1.47 percent. It is worth noting that the error rate in all cases is less than 5%, which is considered acceptable. The findings also show that the suggested method is highly accurate.

(a)

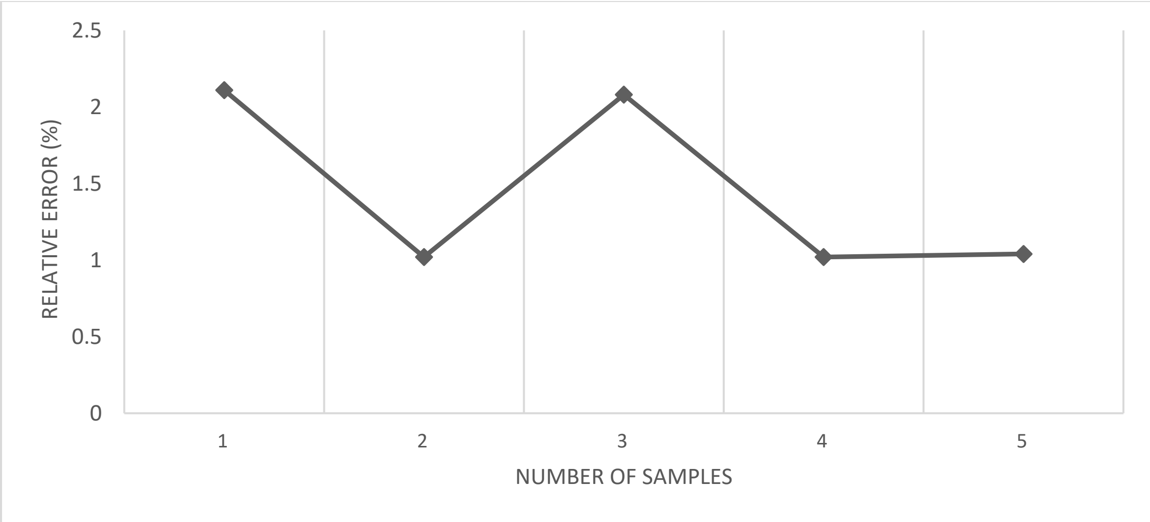


(b)

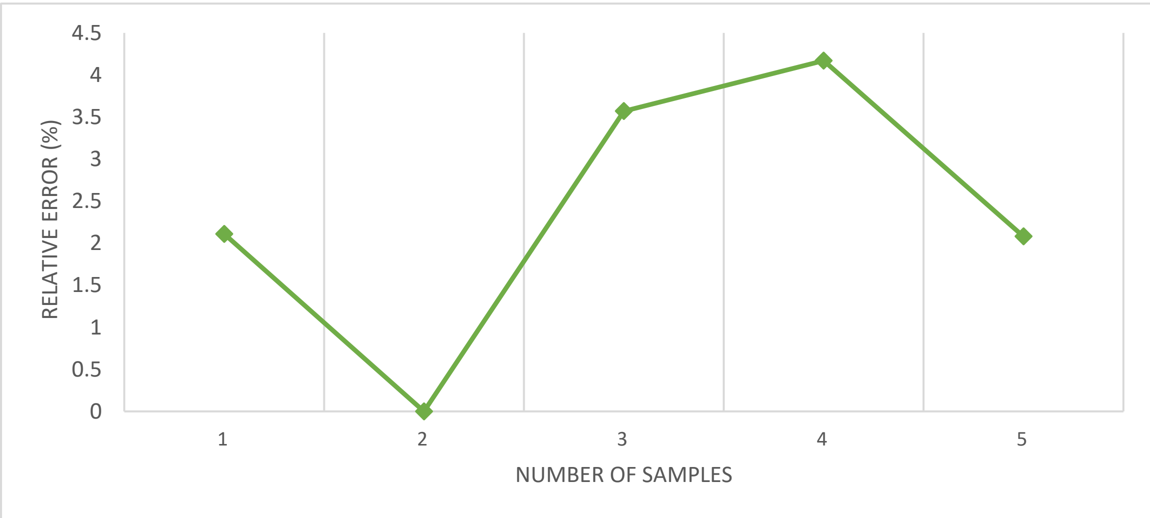


(c)

Figure 10: Comparison of developed system with the commercial devices for (a) SpO2 (%) (b) Heart Rate (bpm) (c) Body Temperature (◦C)



(a)



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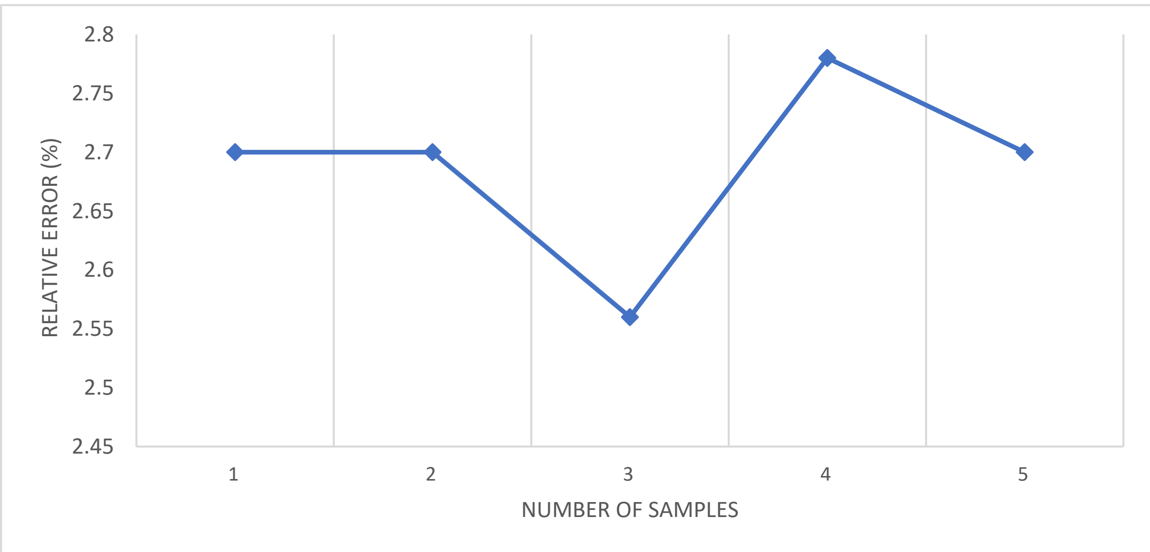


(c)

Figure 11: Relative Error of the proposed system for the case of (a) SpO2 (b) Heart rate (c) Body temperature

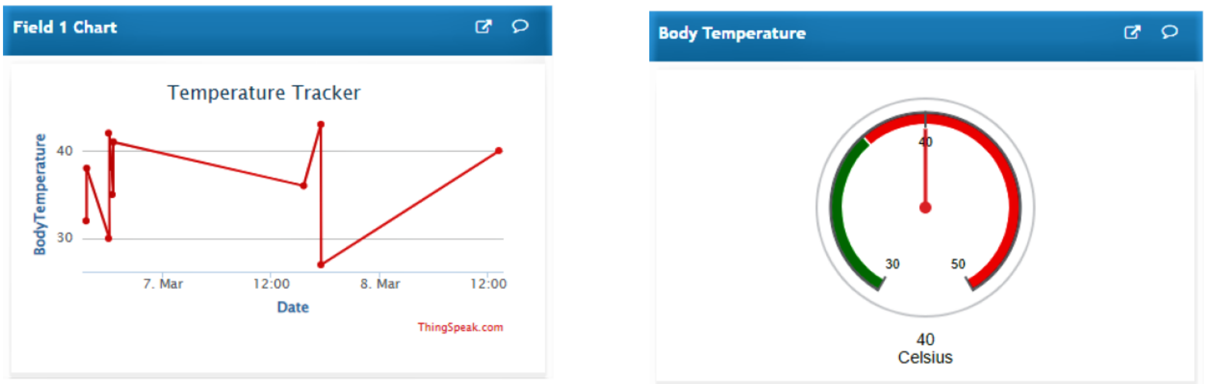
Figure 12(a)-(c) depicts patient data obtained via the proposed system in the ThingSpeak channel. The ThingSpeak channel displays the measured pulse rate, SpO2 level, and body temperature. As previously stated, the normal range for SpO2 is 95 to 100%. The normal range for pulse rate is 60 to 100 beats per minute, and the normal range for body temperature is 36.1 to 37.2 degrees Celsius. If the Covid-19 patient's SpO2 value falls below 95%, he or she should be hospitalized. If the sensor data falls below a certain threshold set by the system, the ThingSpeak server will send an alert email to the user's email address. In this manner, the doctor or patient relative will be easily informed of the Covid-19 patient's emergency status. The patient data is secure in the ThingSpeak cloud server because accessing data requires passing through a password-protected system, which means that only authorized personnel can monitor the system. By analyzing data, a doctor, medical staff, or a patient's relative can easily decide from a remote location or a distant location without any Covid-19 safety measures. This remote feature is not available in [18], [19], which use a Bluetooth connection for patient monitoring and have a range of approximately 10m. As a result, long-distance remote monitoring is not possible with Bluetooth connections, whereas the proposed system employs a WiFi module that allows remote monitoring from anywhere in the world. With MATLAB in the cloud platform of the proposed system, real-time advanced data visualization, analysis, and storage are possible that are not possible in [18], [19]. Another major advantage of the proposed system is its low cost; it costs only $15, which is significantly less than the cost of the commercially available device [9], [10], [12], [39].

Conclusions and Future Works

The proposed system used smart healthcare to monitor the vital indicators of Covid-19 patients such as oxygen saturation level, heart rate, and body temperature. These data are crucial for Covid-19 patients. Early diagnosis of a suspected Covid-19 patient can save many lives in this ongoing pandemic. It will also aid in the monitoring and treatment of quarantined Covid-19 patients. Even if the tests are performed outside of the hospital, authentic medical professionals may examine and track the results in real-time through a smartphone. Thus, using the proposed IoT smart healthcare system, contactless tracing and treatment of COVID-19 patients are extremely feasible. For all the cases of the proposed smart healthcare system, the success percentage between observed data and real data is approximately larger than 95%. The technology is cost-effective (cost 15$), non-invasive, and adaptable, making it simpler to evaluate patients' well-being no matter where they are. Furthermore, it sends real-time email notifications to concerned individuals and medical professionals about any situation that requires immediate attention. The proposed system allows for real-time sophisticated data visualizations, analyses, and storage to track and monitor the patient's health. This strategy can help to ensure optimal medical treatment throughout Bangladesh, especially in rural areas, reducing the number of patients. The new technology will enhance the present healthcare system, perhaps saving many lives from Covid-19 fatality. The primary concerns in this designed prototype are safeguarding the patients' data and making the data available to physicians in a timely and efficient manner. Although the system appears to be fairly big, appropriate manufacturing will result in a compact gadget in the near future. The video option can be introduced for face-to-face consultations between doctors and patients. Machine learning algorithms can be used to detect likely COVID-19 patients from huge populated data sets, minimizing the strain on hospitals and health services.

(a)

(b)



(c)

Figure 12: Covid-19 Patient data monitoring in ThingSpeak cloud server. (a) Heart rate (b) Oxygen saturation (c) Body temperature

Data Availability

Not applicable.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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