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S.I. : NEURAL COMPUTING FOR IOT BASED INTELLIGENT HEALTHCARE SYSTEMS

IoT-based real-time patients vital physiological parameters monitoring system using smart wearable sensors

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Abstract

Health care is one of the least funded sectors in Bangladesh and many other similar developing countries. People living in rural and remote areas do not have access to proper health care, and when they do, it is too expensive. This research aimed to develop a real-time health monitoring system that is cheap, easy to use, and accessible by doctors and patients. The system consists of several Internet of Things (IoT)-based sensors connected to an Arduino microprocessor, which thus measures the vital body signs of the patients. The measured readings are then transmitted to an Android application on a smartphone via a Bluetooth module. The sensors are connected to analog inputs. These sensors measure analog data, which is amplified by the microprocessor after being sorted. Doctors can also carry out the diagnosis of ailments using the data collected remotely from the patient. An Android-based mobile application that interfaces with a web-based application is implemented for efficient patients-doctors dual real-time communication. The Android application, which is connected to a MySQL database, updates the said database, which updates and displays the readings on a website accessible by both doctors and patients. Initially, the health monitor was tested using an Arduino Integrated Development Environment (IDE) monitor and a single user. Once initial simulations were successful, the proposed system was tested on five different real-human test subjects. The testing of the wireless health monitor produced successful results that measured patient vitals with a high level of accuracy. The proposed IoT-based system monitors vital signs such as the patient's body temperature, heart rate, ECG, SpO2 levels, blood pressure, and glucose levels. This system also includes a medical treatment plan by the doctors. The proposed system is novel as it integrates the IoT-based patient monitoring system with telemedicine. This proposed system has different sensors for real-time measuring the vital signs of the human body. A mobile and web application have also been integrated with this system for real-time remote patient monitoring and treatment plan. There are now systems available that only offer a telemedicine facility, where patients and doctors can have discussions, but do not have an IoT-based patient vital sign monitoring system integrated with telemedicine. The proposed system in this paper has the facility of IoT-based patient vital signs monitoring integrated with telemedicine, which makes this research work novel. The proposed system will increase the life expectancy of people throughout the world.

Keywords Internet of things · Wireless health monitoring · Health care · Remote health care · Android application · Patient monitoring · Real-time · Wearable sensors · Smart

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1 1 Introduction

In recent years, there has been a rise in popularity in the usage of IoT sensors for measuring human body vital signs [1]. However, that is not the case for Bangladesh and certain other developing countries. In most developing countries, health care lacks adequacy, and health coverage is non-existent. Health care is not affordable or even accessible in rural areas due to a lack of funding and infrastructure [2]. Thus, people living in remote parts of such countries suffer from a lack of medical check-ups. The number of patients with chronic diseases like hypertension, diabetes, heart disease, Chronic Obstructive Pulmonary Disease (COPD), and others are increasing nowadays. Every year, many patients with chronic diseases die in the whole world. Continuous monitoring of the vital physiological parameters of these patients is crucial. In this case, an IoT-based real-time patient monitoring system can play a vital role.

There are a large number of patients in rural areas who require regular health monitoring (for example, people with diabetes, coronary complications, hypertension, obesity, and other such morbidities). And with fewer than two doctors per 10,000 people [3], patients have to travel long distances and go through expensive medical tests to monitor their health. Thus, currently, the problem is that immediate access to health care is not accessible for rural patients. Even if patients travel long distances to get check-ups, medical tests are too expensive. Thus, there is an immense necessity for producing a cheap wireless portable health monitor that will solve the geographical hurdle and make medical tests available to everyone in the country, thus improving the virtual doctor-to-patient ratio.

The essential part of any shrewd well-being observing framework is to help clients remotely control and check machines. In the very remote rural areas of Bangladesh, the facilities for treatment by MBBS doctors are nearly impossible. Patients from rural areas need to travel to city areas to get medical treatment. In addition to that, in Bangladesh, there are not enough patient seats available in the city hospitals as well. Many patients are lying on the hospital floor and need to wait to get seats on the patient beds. Recently, due to COVID-19, the demand for health care services has increased a lot. Due to the coronavirus, the use of telemedicine has increased. In the COVID-19 situation, continuous monitoring of Covid-affected patients' health is very important. In this situation, an IoT-based remote patient monitoring system would be a blessing for the people. In this Covid time, social removal, less physical contact, and remaining domestic orders are issued by the government to control the spread of the infection. Individuals who have been in contact with emphatically tired people but who do not show any indications are too guided to self-isolate or self-quarantine for a few days. Positive patients with mellow indications are exhorted to watch isolates. The self-isolation or isolation can be watched from home, whereas the influenced individual sends signs or indications of any affliction to the specialist at customary intervals. In Bangladesh, remote health care is still relatively new, but remotely caring for patients has been quite common in the past decade in other developing countries and developed countries. For a lot of reasons, it is still quite difficult to bring quality products to Bangladesh [4]. With this in intellect, the inspiration of this paper is to create a framework that not only controls and screens the well-being of patients but also bolsters the sound way of life of clients. To this conclusion, we are spurred to broaden the scope of the health care system to accommodate the upload of symptoms affected by COVID-19 from the comfort of their respective homes. Vital monitoring and smart sensor usage are supposedly estimated to increase at a rate of 8.76% in the predicted timeline between 2020 and 2027, which is due to reasons like the lower number of health services industry doctors and nurses and due to sub-par government health care policies will hinder the growth of such industry [5]. Any person with non-communicable diseases will be an expected audience for the product, especially those living further away from hospitals.

1.1 Related works

Recently, there have been several different research that has been carried out in the field of health care. Recently, telemedicine has seen immense growth in the last decade in Bangladesh and the rest of the world. Very little research has taken place in Bangladesh about wireless health monitoring, which is IoT-based. Telemedicine does solve the problem of having to travel, but it is not as effective when proper vital sign measurements are not provided to doctors. In other words, they are good for initial first aid [4]. Apollo Hospital allows video calls with doctors without being in the hospital. Patients are allowed access to a variety of doctors, and they can choose whomever they want to visit and pay online [6]. The doctors can send the diagnosis and medication list as a pdf online as well. However, since it still takes quite a lot of effort on both ends, it is quite expensive and difficult to manage a large number of patients. The telemedicine system of Apollo hospital provides only remote patient consultation and prescription services, but they do not provide remote patient monitoring services through their telemedicine system. In Bangladesh, one can find a doctor from anywhere using a service called Tonic Doctor. It is a service presented by Grameenphone. Patients can go to their website and consult doctors directly, similar to Apollo [7]. However, they are limited to diabetes and heart diseases, and they use junior doctors who have passed only MBBS. Also, one has to own a Grameenphone number. Tonic Doctor also provides telemedicine services where patients can discuss with doctors and get basic treatment plans [7]. However, Tonic does not provide any remote patient testing and monitoring systems. Sebaghar in Dhaka, Bangladesh, provides mobile and web application-based telemedicine services. Patients can get doctor consultation and prescription services using this platform [8]. To avail of this telemedicine service, patients need to pay the doctor's consultation fees earlier online. Sebaghar does not provide any medical testing system. It only provides basic medication and prescription services by MBBS doctors. Here, patients can discuss with doctors over a video call using a mobile application or web application of Sebaghar. After the discussion, patients get the prescription from the doctor on their mobile application, which they can download and use [8].

Sparsh and Agarwal portrayed a further well-being checking framework for collecting blood pressure values from patients through a mobile phone. Values recorded on versatile phones are provided and shown to specialists or caregivers through the net interface within the framework. Specialists can screen and oversee the patient's condition through the framework and give input to the persistent remotely [9]. Authors [9] described the pressure monitoring system for remote patients with the help of a mobile phone and web interface. They have not presented the development and testing of any system in this paper. The authors have only described the architecture of the systems. Minh Pham et al. [10] displayed a cloud-based domestic environment named CoSHE for a domestic health care wearable unit, a private cloud, and robot collaborators. The CoSHE framework collects physiological, movement, and sound signals from inhabitants' intensive non-invasive wearable sensors and, in this way, gives data about the day-to-day activities and area of inhabitants within the home. Comprehensive well-being information is given to caregivers and caretakers through a web application built on the cloud server of the system. Moreover, the framework features hydration observing application for persistent observing of water utilization levels and day-by-day liquid necessities of the quiet. Hydration observing is accomplished by utilizing acoustic information collected from amplifiers and body movement settings determined by a smartwatch accelerometer within the framework.

A keen domestic coordinates framework that runs on an Android working framework for surrounding helping living for individuals living with dementia was displayed by Eren Demir [11]. The plan of the framework permits the collection, recording, and transmission of information through cloud applications. The framework includes seven sorts of sensors to identify a person's position, whether standing or sitting, fire discovery, and utilization of indicated apparatuses within the domestic. Also, the sensors remind or alarm the user in case they overlookcarrying out a particular errandon time. A switch is additionally introduced within the system to identify if the light is on or off. The framework is also outlined to distinguish patients' exercises and send information to the specialist or caregiver. Information is recovered from diverse sensors put in particular areas within the domestic for handling. In [11], the authors described the general architecture of Ambient Assisting Living (AAL). The authors did not use any blood pressure monitoring, Electrocardiogram (ECG), heart rate, SpO2, or blood sugar level sensors.

Saiteja et al. [12] proposed a shrewd domestic well-being checking framework for inaccessible observing of diabetes and blood pressure in patients. The framework helps in analyzing the patient's blood pressure and glucose readings from home, sending a notice to the caregiver or health care supplier on the off chance that a variation from the norm is identified, and additionally, foreseeing the status of hypertension and diabetes in patients by preparing the reading. Also, the framework is able to send alarms and real-time notices from domestic around the patient's well-being to an enrolled doctor or clinic. Authors in [12] used a machine learning algorithm to predict patients' diabetes and hypertension status. For the demonstration preparation, back vector machine classification was utilized to supply viable and proficient preparation assignments. The authors did not use any android mobile applications or web applications for remote patient monitoring purposes in this research.

Kashif et al. [5] created a savvy domestic framework based on Data and Communication Innovations (ICT) for the elderly, utilizing an Android stage. The framework was created to make strides in the quality of life for elderly people, anticipate power wastage and protect human vitality at the same time. The framework too controls natural parameters concurring to the well-being status and living needs of the elderly and triggers cautions in the case of interruption and domestic invasion. This paper is mainly about android-based automation, control, and smart house systems [5]. The authors have described the framework. However, IoT-based remote patient monitoring systems have not been covered in [5]. In [13], authors have proposed a patient monitoring system using IoT. The proposed system measures only the ECG of patients using an ECG sensor, and then data are processed using Raspberry Pi. The post-processed ECG data are saved to the IoT cloud. In this paper, the authors also used temperature sensors for the measurement of the body temperature of the patients. They had an integrated SMS system to send messages to the caregivers in case of any emergency. However, this system in this paper has only two sensors, and it does not have any mobile or web applications for remote patient monitoring. Hoe T. Y et al. proposed an IoT-based ECG monitoring system for patients. In this case, the authors used an ECG sensor to measure the ECG of patients [14]. Here, the authors have used the Message Queuing Telemetry Transport (MTT) protocol to send the measured ECG data to the web server. The ECG data can then be accessible by a mobile phone or computer for monitoring purposes. The authors of this paper have also developed an android mobile application to see real-time ECG data. This paper is based on only ECG monitoring of the patient. There was not any web application in this proposed system where doctors could see patients' ECG and provide prescriptions. In [15], Lee et al. proposed a mobile application-based doctor-patient consultation system where there was no real-time patient monitoring system. Patients need to update their vital signs manually. Patients can have a discussion with their doctor via video call. In [16], the authors proposed an IoT-based patient monitoring system. They used a heart rate and SpO2 measurement sensor, an eye blink sensor, and a body temperature measurement sensor to measure the patients' heart rate, SpO2, eye movement, and body temperature. In [16], the system is based on Arduino Uno and cloud computing. The authors have developed a hardware prototype [16] only. However, real-life testing data were not available. In addition, there was a lack of mobile application development and web applications for real-time patient monitoring. A heart rate monitoring system using a mobile application was presented in [17]. In this system, the patient's pulse rate was measured using a pulse rate sensor, and then data were processed using Arduino. The measured data were sent to the android application. In this paper, the number of sensors was limited. This system also does not include a web application where doctors can view the patient heart rate data to monitor and prescribe. Khan M. M et al. presented a smart telemedicine system for the COVID-19 pandemic [18]. The system was based on web and mobile applications where patients could discuss with available registered doctors in the system. A doctor can provide a prescription for the patients. However, there were no medical testing facilities integrated with real-time patient vital signs monitoring [18].

Different researchers have proposed an IoT-based remote patient monitoring system. According to the literature review, it is noticed that there were a limited number of sensors used by the authors. In addition, some systems have only a telemedicine option, and they do not have a patient monitoring system integrated with their system.

The major contribution of this paper is to develop an IoT-based real-time patient vital physiological parameters monitoring system using smart wearable sensors. The proposed IoT-based system measures important body vital signs, including body temperature, heart rate, ECG, SpO2 levels, blood pressure, and glucose levels of the patients. In this research, an Android mobile application has been developed. Various sensors measure different physiological parameters of the patient's body, and these data have been processed using an Arduino microprocessor. Then, the Arduino microprocessor transmits these processed data via a Bluetooth module into an Android mobile application. The Android application feeds these data into a MySQL database, which in turn updates a website accessible by both patients and doctors from the convenience of their current location. A web application has been developed for this system where doctors can register and see patients' information and vital medical, physiological data. Using the web application, doctors can monitor patients' physiological parameters in real time and prescribe to them. Patients receive the prescription and medical treatment plan in the mobile application. In addition, patients can do registration in the website and also view their medical information in real time. After developing the system, it has been tested. Five different real human test subjects with different shapes and sizes were used for testing purposes. The sensors used in this research give accurate results, which commercially available medical devices have also verified. The proposed IoT-based wireless health monitoring system is cheap, light (portable), and easy to use.

The development of an IoT-based real-time patient vital physiological parameters monitoring system using smart wearable sensors in this paper is novel. According to the literature review and to the authors' knowledge, this type of novel research work in this paper has not been done before. In this paper, the number of sensors is more than any work presented in the open literature so far. Currently, there are systems available that have only telemedicine where patients and doctors can have video discussions, but they do not have an IoT-based patient vital signs monitoring system integrated with it. In addition, there is some literature where authors have used very few sensors, and they have transferred the data to the cloud. No web application has been developed for real-time patient monitoring and treatment planning. Authors in some papers just discussed the framework of the IoT-based remote patient monitoring system. In addition to that, the sensors and the systems used in other papers have not been tested comprehensively, and the data have not been verified. The proposed work in this research paper is comprehensive. There are many required vital sensors, a mobile application, a web application, many features, and the whole system is tested. By considering the above-mentioned facts, the proposed system in this research work is novel. Thus, the novelty of this research work beats the state-of-the-artwork.

The paper is set up as such in the following way: The second section gives a detailed description of the design and architecture of the entire application. Section 3, on the other hand, describes and interprets the results found from the testing phase of the hardware and software implementation. The results are then discussed in comparison with the theoretical perspective, and the conclusion and other future developments are discussed in Sect. 5.

2 Materials and methods

The term temperature indicates earmarks of hotness or coldness of the body. Normally, it refers to the impact such as temperature on helping or impeding warm by radiation and convection from the portion. Commonly, the temperature is surveyed by a thermometer at a particular position on the body. Normally, the temperature of the body is between 97.5 Fahrenheit and 99.7 Fahrenheit. B.P-Blood weight could be an estimation of the constraints applied to the divider of an individual supply route as his or her heart pumps blood into his or her body. The perusing gets by two numbers. The beat number is systolic, and the foot number is diastolic. This is an estimation of the constraint applied to the divider of an individual supply route as his or her heart pumps blood into his or her body. The perusing gets by two numbers. The beat number is systolic, and the foot number is diastolic. For instance, 140 over 80 is written as 140/80 mm Hg [19]. The pulse rate may be an ordinary condition of resting heart rate for grown-ups of 60 to 100 m per minute. The beat is getting lower, whereas grown-ups are at rest or expanding when working out. The beat rate shifts from individual to individual. An electrocardiogram (ECG) could be a straightforward test that can be utilized to check one's heart cadence and electrical movement. It stands for detecting one's heart rate and rhythm [19]. Glucose is a key element of our body that keeps our body instruments in the best working arrangement. It is the only carbohydrate that makes it a monosaccharide. It connotes that it has one sugar, and it's not alone. Other monosaccharides incorporate fructose, galactose, and ribose. Testing glucose levels is important for diabetic patients. Regular checking is necessary for such patients on a daily routine basis. Generally known as an oxygen immersion, Spo2 could be a measure of the sum of the oxygen-carrying hemoglobin within the blood relative to the sum of hemoglobin not carrying oxygen. To work proficiently, the body needs to have a certain level of oxygen in the blood. In genuinely, an exceptionally low level of Spo2 can result in exceptionally genuine side effects, which is known as hypoxemia [19].

The design of the wireless health monitor had to be such that it would have had to be able to measure temperature, heart rate, ECG, SpO2 levels, blood pressure, and glucose levels. So the hardware needed to be compact and light. For it to be portable, it would have to run on a Direct Current (DC) power supply. Thus, sensors connected to an Arduino microcontroller were used to measure the vital signs. A Bluetooth module was used to transmit these measured data wirelessly to an android application (built using JAVA in the android studio) from where a MySQL database was updated with the information. Then, the patients and doctors could access the information through a built-in website updated by the same database. The best option for quick and efficient website development was Hypertext Preprocessor (PHP). This Patient Health Monitoring system comprises both a hardware part and a software part. Along with the software part, a database on a web server as a storage for the accumulated data from the hardware implementation was being used.

2.1 Design plans

2.1.1 Hardware architecture

There were three different sections. The microcontroller is at the center of the entire hardware process. It receives analog signals from the sensors, and then, the Arduino code is written such that the data are sorted from each sensor and then digitized. The sorted data are then passed on to a Bluetooth module which transmits the data to the mobile android application. The android application displays the readings and simultaneously updates the MySQL database connected to the website. From the website, patients and doctors should be able to access the information simultaneously.

2.1.2 Android application and website interface integrated with database server

When patients open the application, they should be prompted to register and open a new account with their personal details, which will be passed on to the database. The application system will always check the database for these login details to allow patients for future logins. Once logged in, patients should be able to do the following: They should be able to view their past readings to compare, they should be able to take new measurements, or they should be able to check their doctor's prescription that was given since the last time they took readings. Figure 1 shows the architecture of the algorithm that will be used for the android user interface (UI). After the patient logs in, patients can choose between two options. One alternative is to upgrade the data of patients by giving data approximately title, age, crisis email, and ID, which is really the

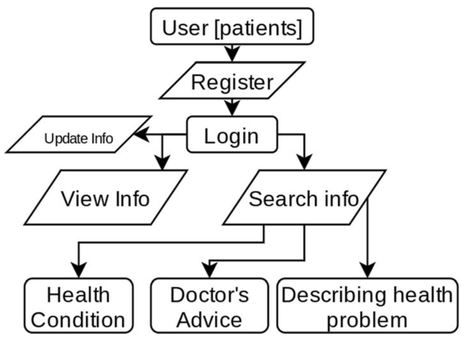


Fig. 1 Block diagram of proposed android UI implementation

device ID, and, of course, the interesting id for each persistent (Fig. 2).

Another choice is to see data which are the whole data of the patient's current health condition. This choice will show the temperature and beat rate. It too will show any advice from specialists. Besides, understanding can portray his/her well-being condition by either selecting given symptoms or portraying problems in a chosen box that can specifically reach the doctor's application.

Similar to patients' applications, specialists can begin by generating an unused account on the doctor's application. After that, the professional would be able to use his account. Specialists must once again register their account by including the basic information needed to access the account and then log in with their username and password. This section's whole mechanism is shown.

A doctor may have a large number of patients under his care. As a result, a doctor will have access to a list of patients the specialist will see. More specialists may choose a single permanent by selecting it from the understanding list by clicking on the title of the understanding.

Specialists would be able to view all of the patients' records after clicking on a single patient. He'll still be able to see if some form of signal or warning is sent to specialists. Specialists may recommend specialists based on their findings. There is an option called "delete permanent records." It means, if a specialist needs it, he can erase a few past records of a persistent person.

The probable flow of server implementation is shown below. The Bluetooth module can be utilized as equipment, and it'll be set up with the Arduino so that it can exchange information over the Internet. A computer interface can handle questions utilizing http, the most well-known convention for trading information on the World Wide Web. The information will be put away, handled, and sent to clients. A Bluetooth module will be utilized to exchange information with the app, and a web server will be utilized to store data. The Android interface was selected for the smartphone gadget. Android encompasses a world-class stage for creating apps and diversions for Android clients all over the world, as well as a free commerce center for disseminating them right away [20].

Prophet Enterprise disseminates, creates, and keeps up the MySQL database, an open-source, commonly utilized, and most well-known SQL database administration framework. The MySQL database administration system will be included in this article. MySQL too has the good thing about supporting social databases [20]. Consequently, it is exceptionally adaptable to use since data can be put into totally different tables instead of putting all the data into one table. Figure 3 shows how the database was structured.

In program execution, the program portion is coordinated with the equipment portion. The equipment portion has an Arduino, ECG sensor, Heart Beat Sensor, Bluetooth Module, and LCD display. To execute the equipment portion, the code may well be planned such that the heartbeat stick is initialized in stick 7, the heartbeat button is initialized in stick 6, and the ECG button is initialized in stick 2. When starting to organize, the value of ECG and

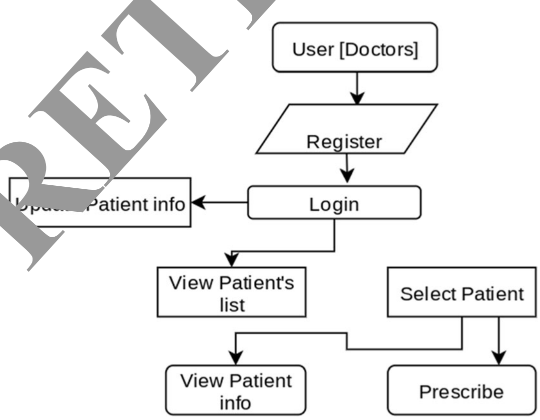


Fig. 2 Flow diagram of proposed patient UI implementation

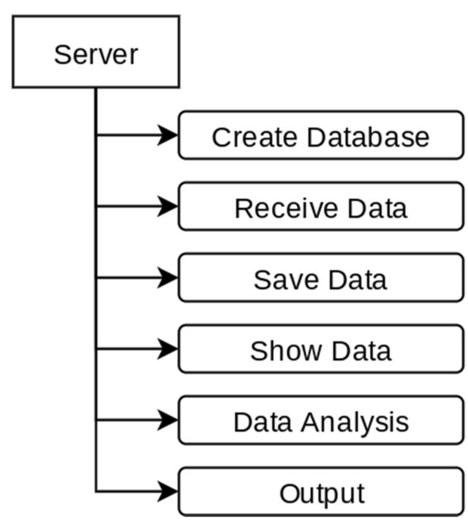


Fig. 3 Block diagram of the proposed server implementation

heartbeat are 0. A strategy setup is utilized for setting up the LCD's number of columns and columns. Here, the button is taken as input. A call-back strategy is utilized to not hinder when the heartbeat is tallied for 20 s. It is executed in 1 moment. Figure 4 appears in the square chart for the whole health monitoring process.

To execute the site, the paper coordinates the equipment with benefit calls to appear on the site. In real-time, esteem appears on the site. We made a web front with a gadget interface. The (Hypertext Preprocessor) PHP/JavaScript dialect is utilized for making the site. PHP is utilized to call the server and get the information from the server. When a heartbeat is measured on a pulse sensor, it is transferred to the server and appears as genuine esteem on the site agreeing to the date and time. It moreover creates the ECG bend graphically on the site, concurring with the time and date. Chart.js may be an effective information visualization library. It is utilized to make the graphical lines on the site. The web benefit is utilized to display ECG graphically by calling information from the server and creating it from the Arduino code. In other parts, one can also make a live check of the understanding by utilizing a login username and password.

2.2 Implementation

The following items shown in Table1 were bought for the entire implementation of the hardware implementation. Table 1 shows the list of required equipment and the price of it. The price here is given in Bangladeshi Taka. The total cost of the hardware components for the development of the proposed system is 5735 Bangladeshi Taka, which is equivalent to 67.50 US dollars. From the table, it is noted that the hardware equipment for the system is very cheap. That makes the whole system cost-effective, which will be good for the general public to buy and afford the system.

The details of the equipment and how they are connected to the microcontroller for each sensor are given below.

The Arduino Uno, shown in Fig. 5 could be a microcontroller based on the ATmega328P (datasheet). It has everything required to bolster a microcontroller. It has 14 advanced input/output pins (can be utilized as PWM yields), 6 analog inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a Universal Serial Bus (USB) association, a control jack, an ICSP header q, and a reset button. So it can essentially be associated with a computer with a USB cable and control with an AC to DC connector or battery so that it can be started.

The AD8232ECG ECG MODULE, shown in Fig. 6, is coordinated with the AD8232 IC from Analog gadgets. It is outlined as a single chip so that it can extricate, open up, and channel signals for bipotential estimation applications (like ECG and others). The ECG may well be exceptionally loud. That's why the AD8232 Single Lead Heart Rate Screen acts as an op-amp, making a difference in easily getting a clear flag from the PR and QT Interims. For feature extraction, crude ECG information is sifted and

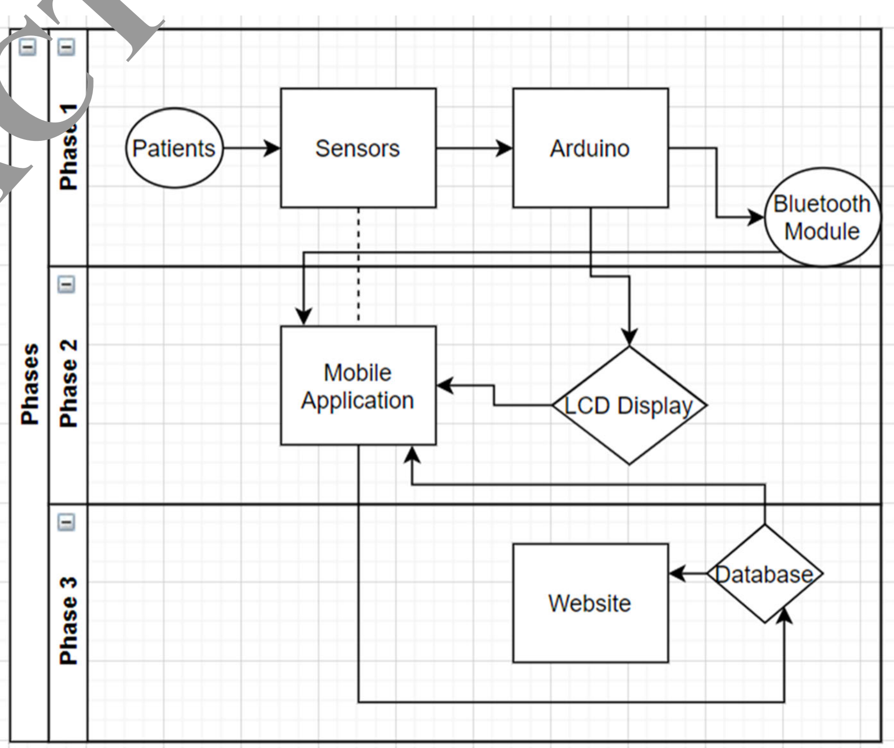


Fig. 4 Block diagram for the entire health monitoring process

Table 1 Types of equipment used in the proposed system

Item	Price(BDT)
AD8232 ECG measurement module	1199
Arduino bluetooth module HC-06	279
Arduino uno R3 SMD	349
Breadboard	99
High accuracy 12C MAX30105 PARTICLE optical sensor oximeter module	2300
Jumper wires	90
L7805 voltage regulator	10
LCD keypad shield arduino	350
LM35 temperature sensor	320
Rechargeable battery charger	299
9v Sony rechargeable battery	440
Total price	5735

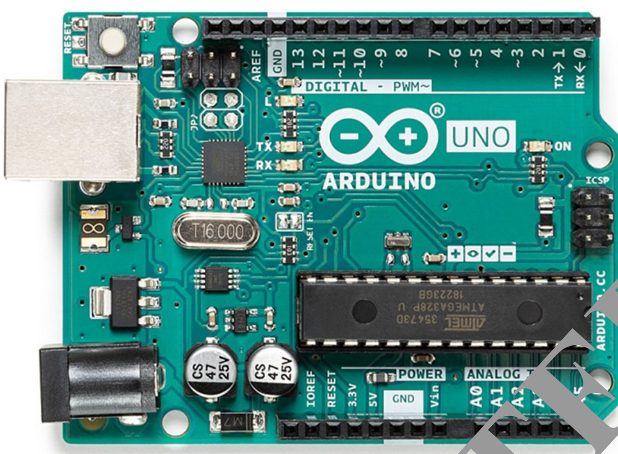
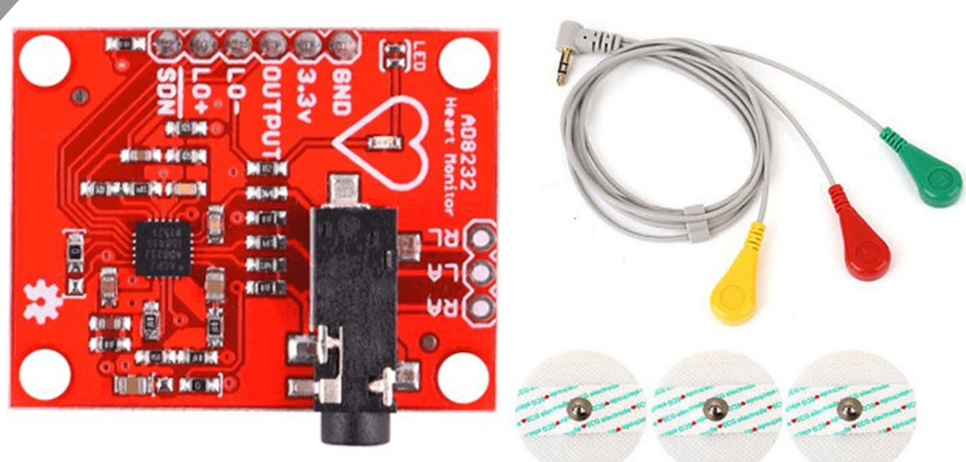


Fig. 5 Arduino Microcontroller Pins [21]

sectioned, and after that, a complexity examination is performed. Combining a stack-based classification module and a relapse module, a machine-learning strategy is connected to building systolic BP(SBP) diastolic BP (DBP).

The MAX30105, shown in Fig. 7, is an indispensable molecule detecting module. There are inner LEDs, photo finders, optical components, and moo clamor hardware encompassing light dismissal. A total framework arrangement that can ease the design-in handle of beats and oxygen level detecting is given within the MAX30105. Because it is amazingly small, it can, moreover, be utilized as a wearable gadget. Having an electronic show module, an LCD employs fluid precious stones to create an obvious picture. Exceptionally commonly used in DIYs and circuits, the 16 × 2 LCD display is a case of a really fundamental module. 16 × 2 outlines a display of16 characters per line in such 2 lines. This paper, too, encompasses an unused equipment framework that can measure the glucose concentration in the blood. This framework is really non-invasive, speedy, and basic. To begin with, near-infrared light is utilized in this paper. The infrared light transmittance here can get the flag of blood glucose concentration. Then, these signals will be transmitted to Arduino after amplification by an amplifier. The



(a) (b)

Fig. 6 ECG sensor connection [22]

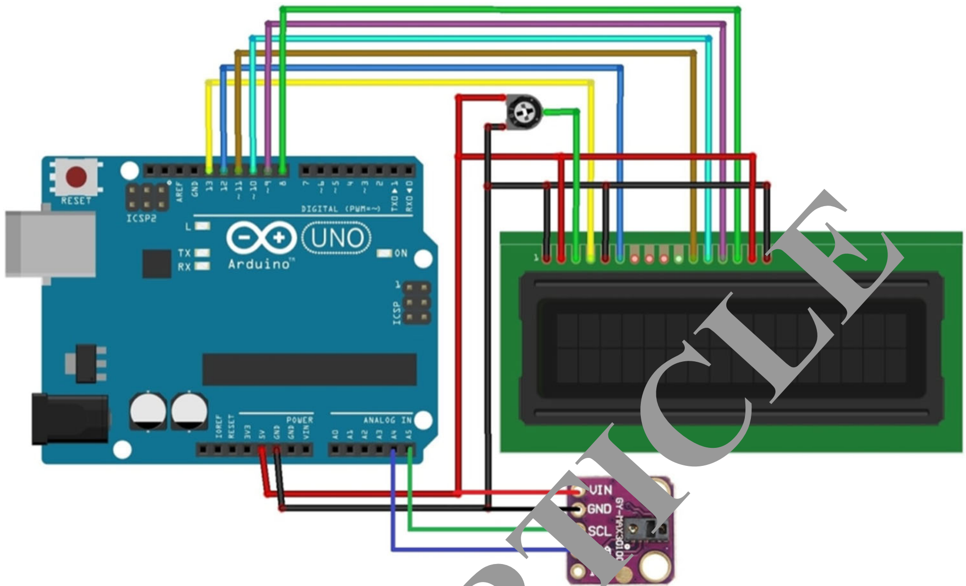


Fig. 7 Particle sensor connection [23]

Arduino Uno board has a CPU that can analyze and process signals. By comparing with a standard set, the system can determine the blood glucose concentration of the signals. Lastly, the result will appear on the LCD screen, which can also be transmitted to a phone via Bluetooth at the same time.

LM35, which appeared in Fig. 8, could be a temperature sensor that can measure temperatures within the range of −55 °C to 150 °C. It may be a 3-terminal gadget that gives an analog voltage corresponding to the temperature. The higher the temperature is, the higher the yield voltage [24].

The HC-05 Bluetooth module, shown in Fig. 9, could be a stackable shield with serial ports based on the HC-06 module. The shield can be associated straightforwardly with the Arduino UART harbor for remote communication. Without deterrents or other impedances, the Bluetooth shield can communicate for a run of 10 m (32ft) [25].

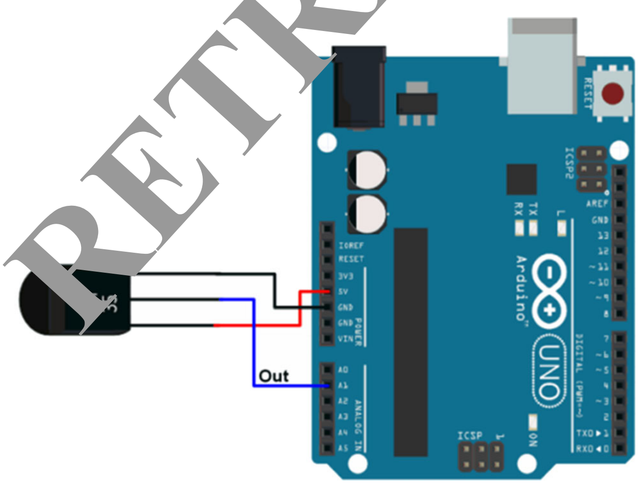


Fig. 8 LM35 Temperature sensor connection [25]

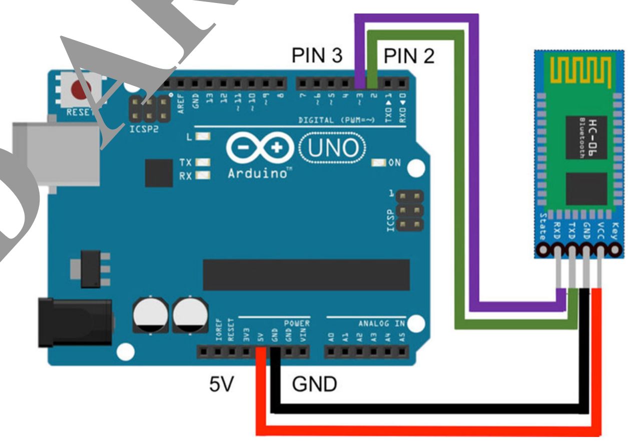


Fig. 9 Bluetooth module connection [26]

The Arduino and Android applications are connected via Bluetooth. JAVA code is used by the android studio for the android application to send some data to the application. Arduino decides and provides data according to user preference from the incoming value. Then, Arduino takes readings from the sensors and transfers them using HC-05 to Android. Android receives the data and sends it to the real-time database. Figures 10 and 11 show the database structure for doctors and patients, respectively.

For the database management system, MySQL is used, which is currently the most popular database management system out there. MySQL is an API that uses a connector function to link the backend of the PHP app to the MySQL database. It provides a better set of functions and extensions. MySQL was used to connect to a PHP-designed website [28]. On the other hand, a simple API was used to connect Android apps to the MySQL server.

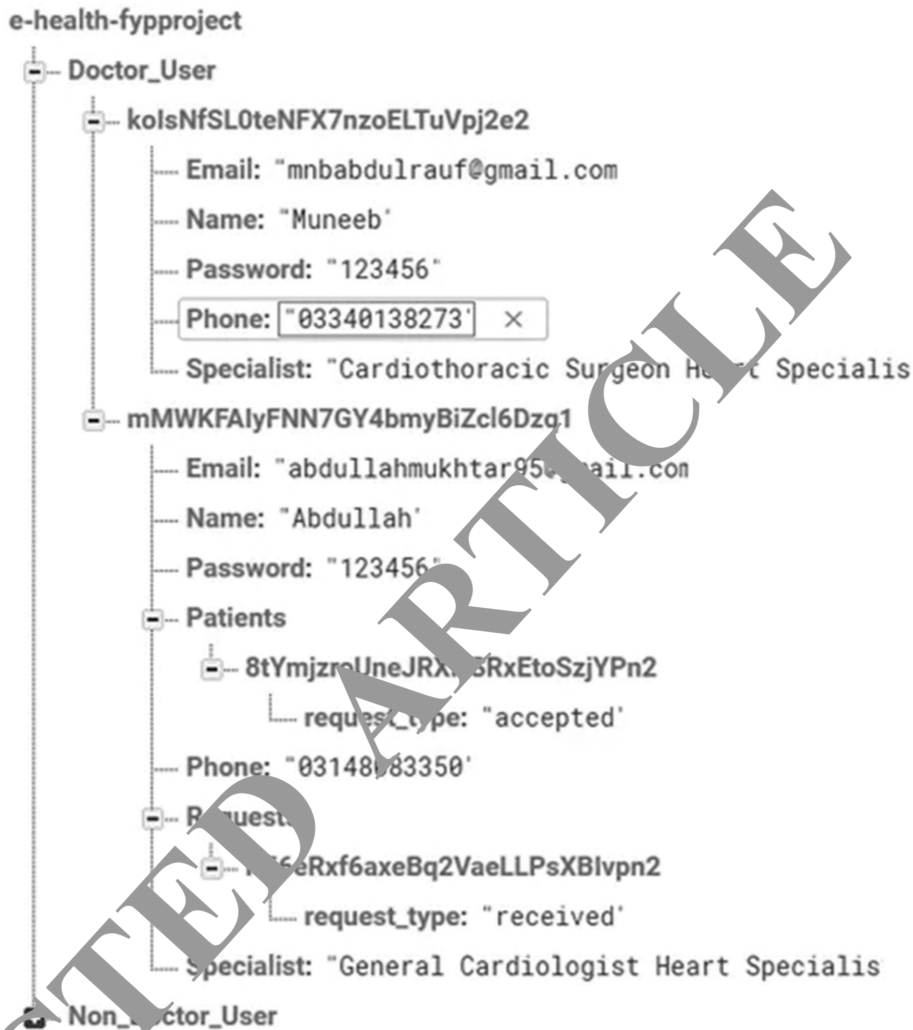


Fig. 10 Patient's database structure [27]

3 Results and analysis

Figure 12 shows the final hardware prototype built for the proposed IoT-based patient monitoring system in this research work. The hardware was built by using a bread-board as the connecting platform for the wiring of the machine. No final casing of the machine was built as this paper represents the working prototype to measure the accuracy of vital sign readings. Here, the sensors and the connection of all sensors with the Arduino and other required components are shown. In this hardware prototype, all the required sensors are connected to the Arduino. Sensors will measure the analog signals from the human body, and then, Arduino will process the measured data and provide a digital output which will be sent to the mobile application via Bluetooth device. The ECG sensor used for this system has three leads, which are also included with the hardware prototype. For the commercial purpose of the system, a mold can be used for the coating purpose of the whole hardware system.

3.1 Measurement of accuracy of sensor readings

Once the hardware was built, the initial simulations were done using the Arduino IDE monitor. The physiological parameters of humans were measured and displayed on the monitor, as shown in the following figures. The accuracy still remained to be measured in this phase. In this case, for the testing and measurement of the developed system, a real human test subject was used, as shown in Fig. 13. Figure 13a shows live testing of the system on a real human test subject. Figure 13b shows how the ECG is plotted on the serial plotter. The signals are generated as voltages of electron movements across arteries. Each pod measures the voltage, the data of which is passed on to the analog input of the microprocessor. This signal is amplified to produce a graphical representation on the monitor.

Like the serial plotter, the monitor shows the readings but in a graphical form. Each of the vital sign values for each pulse appears in tabular form, as shown in Fig. 14 as

Fig. 11 Doctor's database structure [27]

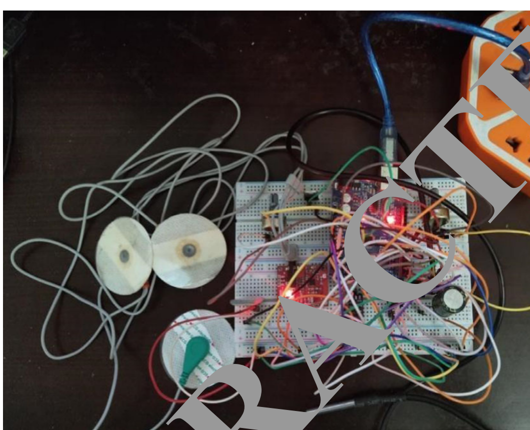


Fig. 12 Working hardware prototype of the proposed system built for testing purposes

follows. The analog input values before the graph is plotted can be viewed on the serial monitor as follows.

In this study, in order to test the system, more measurements were performed. A sample size of 5 real human test subjects was used for testing, measurement, and comparison purposes. In this case, these measured physiological parameters' values were manually noted down, and the data were entered into a Google sheets application to compare with values measured by accurate machines to produce a deviation of values from original measurements. The following graphs show original, accurate measurements versus the measured values from the hardware sensors proposed in this paper. The graphs below, shown in Figs. 15, 16 and 17, were graphed in Microsoft Excel after manually noting down each value from the serial monitor and then graphing these values against values of vital signs measured medically. In Fig. 15, the orange color bars in the graph show the measured temperature values for five different test subjects that were obtained using the proposed temperature sensor of this system, while the red color bars in the graph shows the measured temperature values using a commercially available analog thermometer. In Fig. 15, the X-axis represents the test subjects. Temperatures were graphed against those measured using a thermometer. In this case, the results of the temperature of the proposed sensor are compared with the analog one. The thermometer here shows the body temperature in degrees Fahrenheit (^{0}F).

Pulse rate and oxygen saturation levels were graphed against values measured with a pulse Oximeter sold in the current market. Figure 16 shows the measured pulse rate values (pink) versus medically collected values (blue) for five different test subjects. The pink color bars in Fig. 16 show the measured heart rate values that were obtained using the proposed heart rate sensor in this study, while the blue color bars in the same graph show the heart rate values that were obtained using commercially available pulse Oximeter sold in the local market. The unit of the pulse rate in Fig. 16 is BPM (Beats Per Minute). Figure 17

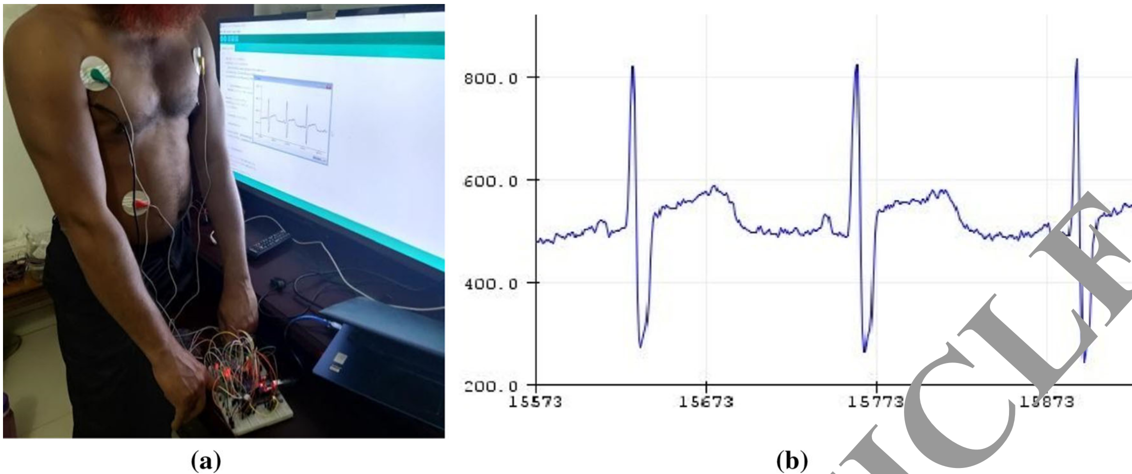


Fig. 13 Initial Arduino simulations for ECG values. **a** shows live testing on one of the patients while **b** shows the ECG plot on the serial plotter

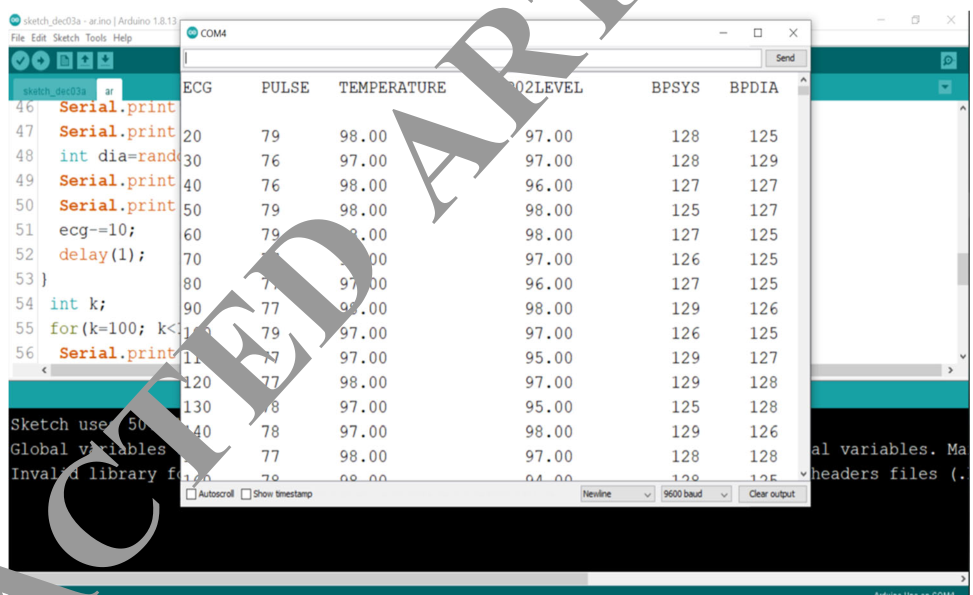


Fig. 14 Serial plotter showing values of physiological parameters measured from sensors

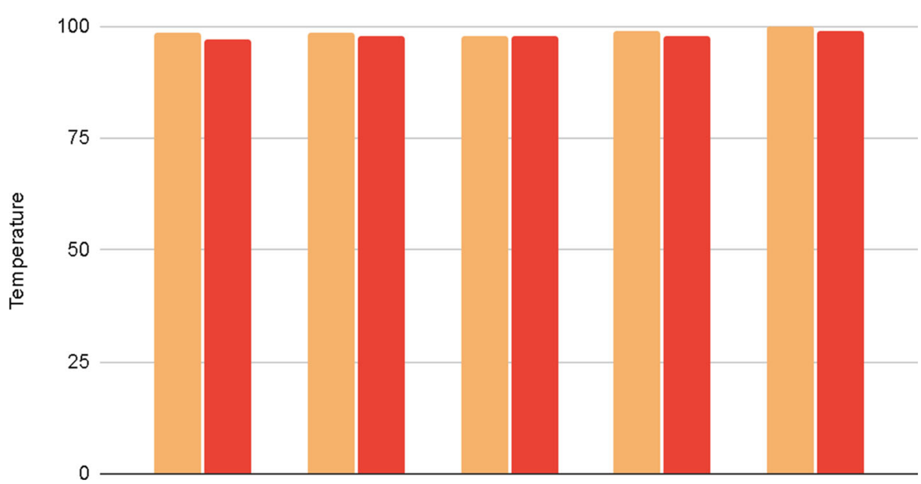


Fig. 15 Measured temperature values (orange: sensor of [illegible] study) versus medically collected values ([illegible] analog thermometer commercially available) for five different real human test subjects. X-axis represents the test subjects. Temperature is in degrees Fahrenheit (^{0}F)

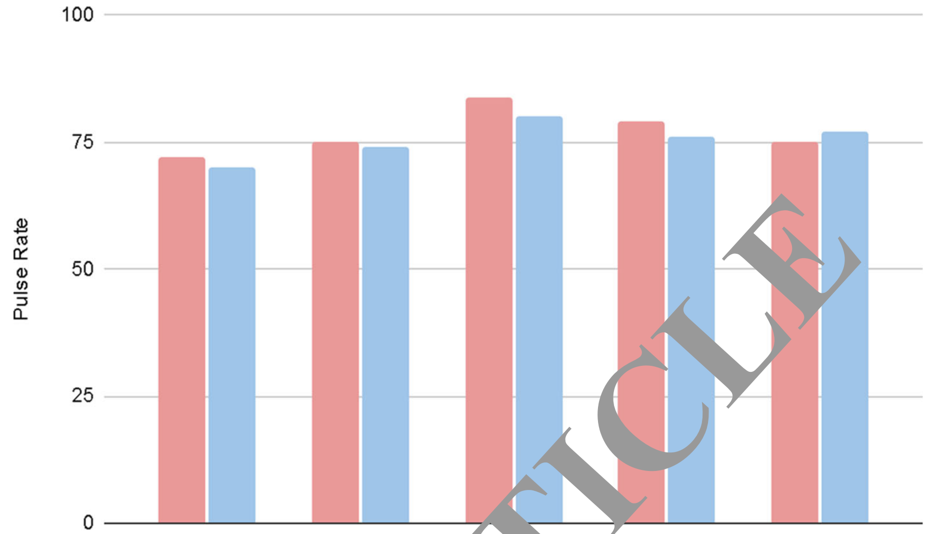


Fig. 16 Measured pulse rate values (pink) versus medically collected values (blue). X-axis represents the test subjects. Pulse rate is in BPM

Fig. 17 Measured blood oxygen level values (green) versus medically collected values (pink). X-axis represents the test subject

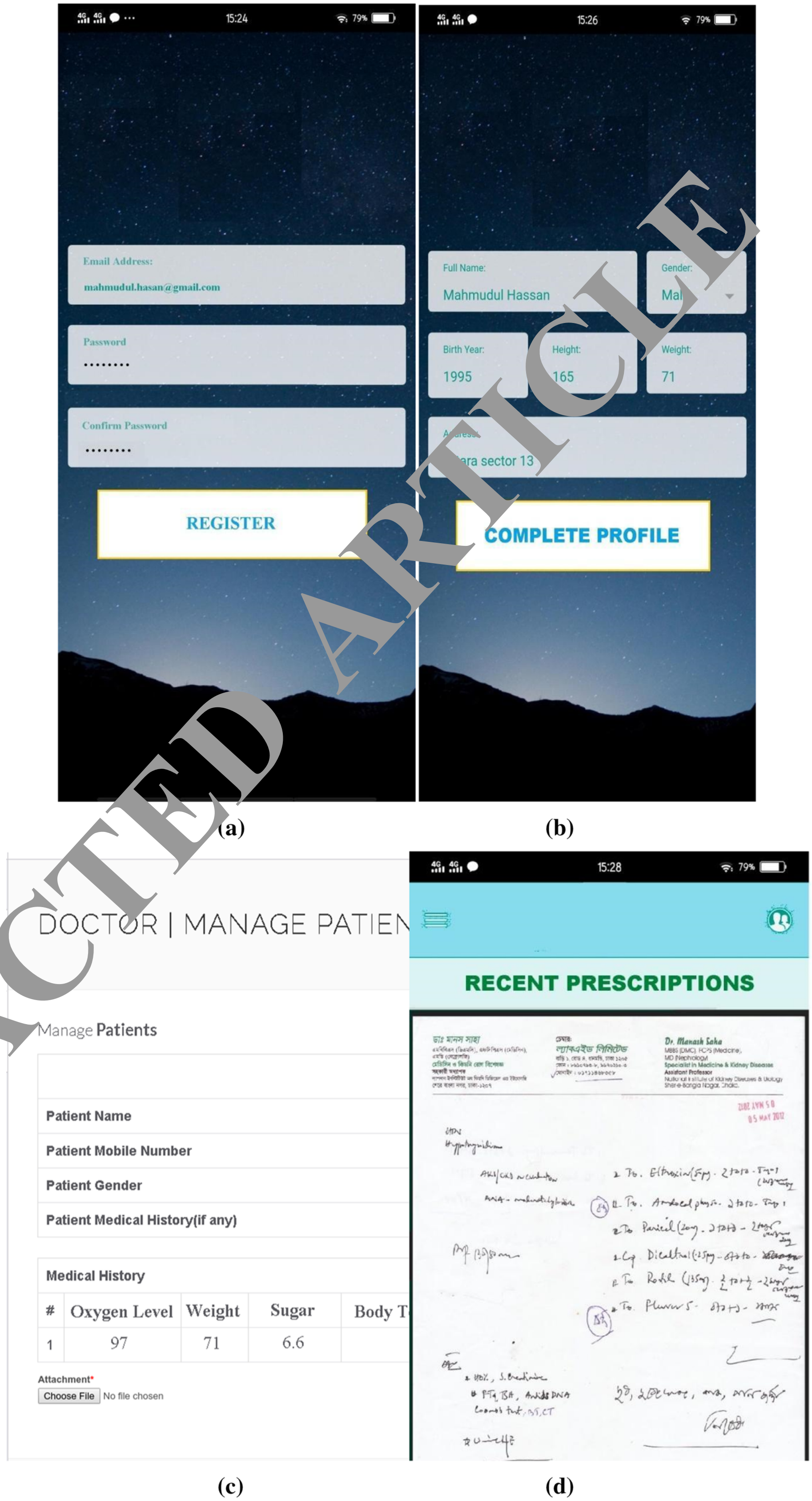
shows the measured blood oxygen level values (green) versus medically collected values (pink) for five different test subjects. In Fig. 17, the green color bars of the graph show the measured blood oxygen level values using the proposed sensor in this study, while the pink color bars of the graph show the measured values using a commercially available pulse Oximeter sold in the local market. Each separate bar in the following graph represents each separate patient. In each graph, corresponding bars show vitals measured using medical equipment versus the measurements taken by the wireless health monitor mentioned in this paper. Manually, each of the readings was measured, noted, and then graphed against medically measured values to compare the bars. In Figs. 15, 16, and 17, the X-axis shows the test subjects that were used for measurement purposes in this study.

To measure the accuracy, the percentage difference in the value of the vital was calculated. From the above graphs and plots, we can see that most readings were well within the 10% error rate. Thus, most vital measurements were accurate to above 90%. Some readings were even as close as 98% accurate compared to vital readings measured by current market products. This was considered to be quite accurate when compared to the prices of products in the market. These results were good when looked at from a financial standpoint.

3.2 Android application testing

This phase includes an individual patient's process to see, record, and share their vital medical history on the android application. Once the above readings are taken, they are viewed on the android mobile application by the patient. But before one can do that, one needs to register their account, and they will go through a series of fields to fill in and give their personal details. Figure 18 shows the simplistic registration process for the mobile application. Once the patient opens up the mobile application, he/she has to

Fig. 18 The registration process for Android application users. **a** shows how a patient first has to login by registering their email and **b** shows the completion of the profile once logged in. **c** shows the prescription attachment button on the website, while (d) shows how the pdf prescription appears on the android app



register by filling in the required information, as can be seen in Fig. 18a-b. These fields are saved in the database and used for authentication. Once an account is created, patients can login using a username and password that they selected themselves during the registration procedure.

Once logged in, patients will have to connect the application to the Bluetooth module, which is quite simplistic. Once searched, they will find a device to be paired named HC05 or see the mac address for it. Once the pairing request is sent, the pairing takes only about 3 to 5 s, and a notification will be shown to the user. In the Android mobile application, patients can also see the prescription provided by the doctor from the web application. After logging in to the web application, a doctor can monitor patients' medical information and testing data in real time and provide the prescription to the patients. The prescription form for the web application needs to be attached by the doctor. Figure 18c shows the prescription attachment button on the website. Here, at the patient's end, users can see their prescription in the mobile application in pdf format. Figure 18d shows how the pdf of the prescription appears on the android application.

Once pairing is confirmed, the monitor section of the app will show the readings automatically as long as the person is connected physically to the sensors. The sensor readings will show up in the application. Once readings are taken, they are saved automatically on the MySQL database under the names and identities of the patients. That is done in the background through a backend API call. The patient does not have to save anything. The patient also has the option to change personal details or check up on his or her prescription. Only the most recent prescription is shown on the application.

Figure 19 shows the live testing of the mobile application with the whole sensors and hardware prototype and a real human test subject. The Android mobile application successfully shows the measured vital physiological parameters of a real patient. The proposed hardware prototype and android mobile application of the proposed system work perfectly. The hardware prototype can successfully send the measured data from the human body to the mobile application. The android applications show all vital parameters (heart rate, SpO2, ECG graph, blood glucose level, blood pressure, and body temperature) of a real human test subject on the mobile application (Fig. 19). The measured data here in the mobile application also show accurate values. Data accuracy has already been discussed in the previous section. Apart from certain bugs and certain User Interface (UI) changes that could be made, the application runs smoothly and accurately. Figure 19 shows the implementation of the android application. Once pressed on the monitor button, the android window will ask to connect the sensors, which, when connected, will pass over the values to the android app. Each of the vitals will show up in relevant fields, and the session data are automatically recorded to be sent to the database from where the website is updated. The prescription button on the android app displays a pdf of the prescription uploaded by the doctor on the website.

3.3 Database

The MySQL database is immediately updated with the information provided by the user. The backend API call pulls the user information from the android device into a structured database. Once in the database, the android application can use the database to check login or other credentials. The figure below shows that the patient's information has automatically been added to the MySQL database along with all the personal credentials. Figure 20 shows the database structure of a user's saved information.

The doctors, however, do not have an android application for the purposes of this paper. They can access the database information via a connected website where they too would be required to give their personal details and credentials. Their details are also stored in the database under the doctor's tab. The database also contains all the readings for the patients in the logs tab, as seen on the left-hand side of the image in Fig. 20. The website can allow both doctors and patients to access these details.

3.4 Web implementation

To actualize the site, equipment was coordinated with benefit calls to appear on the site. The real-time esteem within site. Figure 21 shows a screenshot of the website's home page. A web front with a gadget interface was made. The PHP/JavaScript dialect was utilized for making the site. PHP is utilized to call the server and get the information from the server. When a heartbeat sensor measures the heartbeat, it is transferred to the server and appears as genuine esteem on the site, concurring with date and time. It too produces the ECG bend graphically on the site, concurring with the time and date. Chart.js could be an effective information visualization library. It is utilized to make the graphical lines on the website. On the front end of the website, doctors, patients, and admins can do registration, and they can also log in to the web application. Figure 22a-b shows the doctor and patient registration and login pages of the developed web application in this research work. In Fig. 22a, a patient login system is shown where a patient can log in to the web using their email address and a preferable password set by the patient himself. In Fig. 22b, a doctor login system is shown where a doctor can log in to the web using an email address and a preferable password set by the doctor himself. If patients

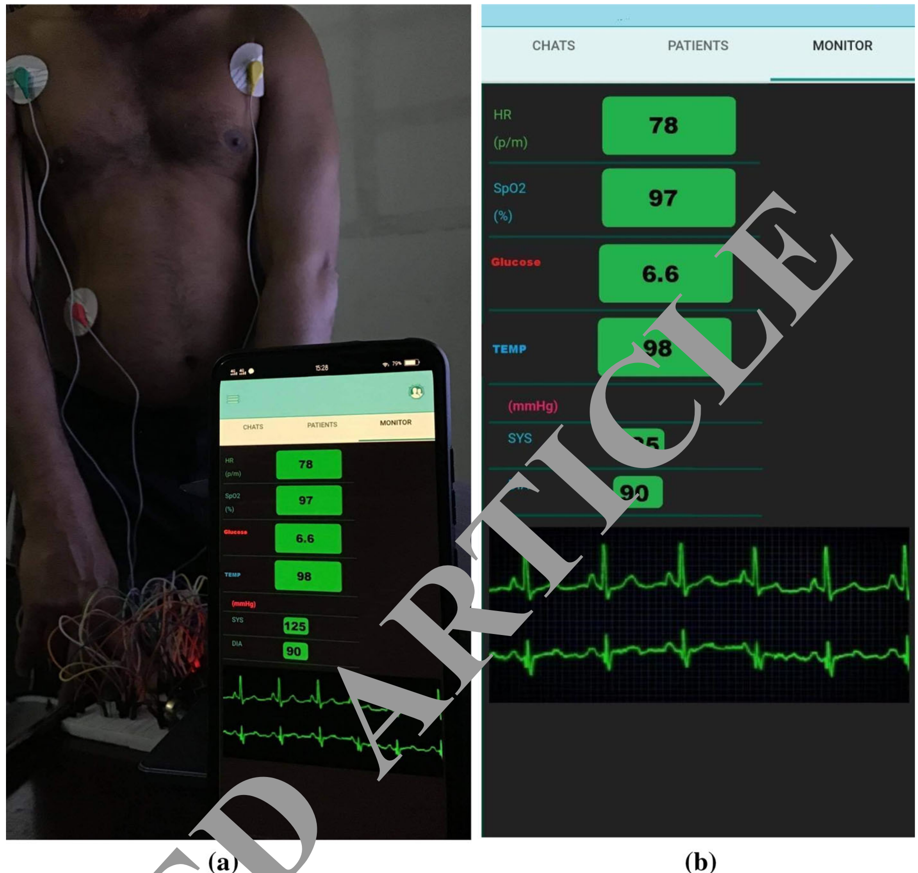


Fig. 19 Testing of mobile application **a** shows the live testing of one of the patients, while **b** shows how the vital physiological parameters can be read from the mobile application

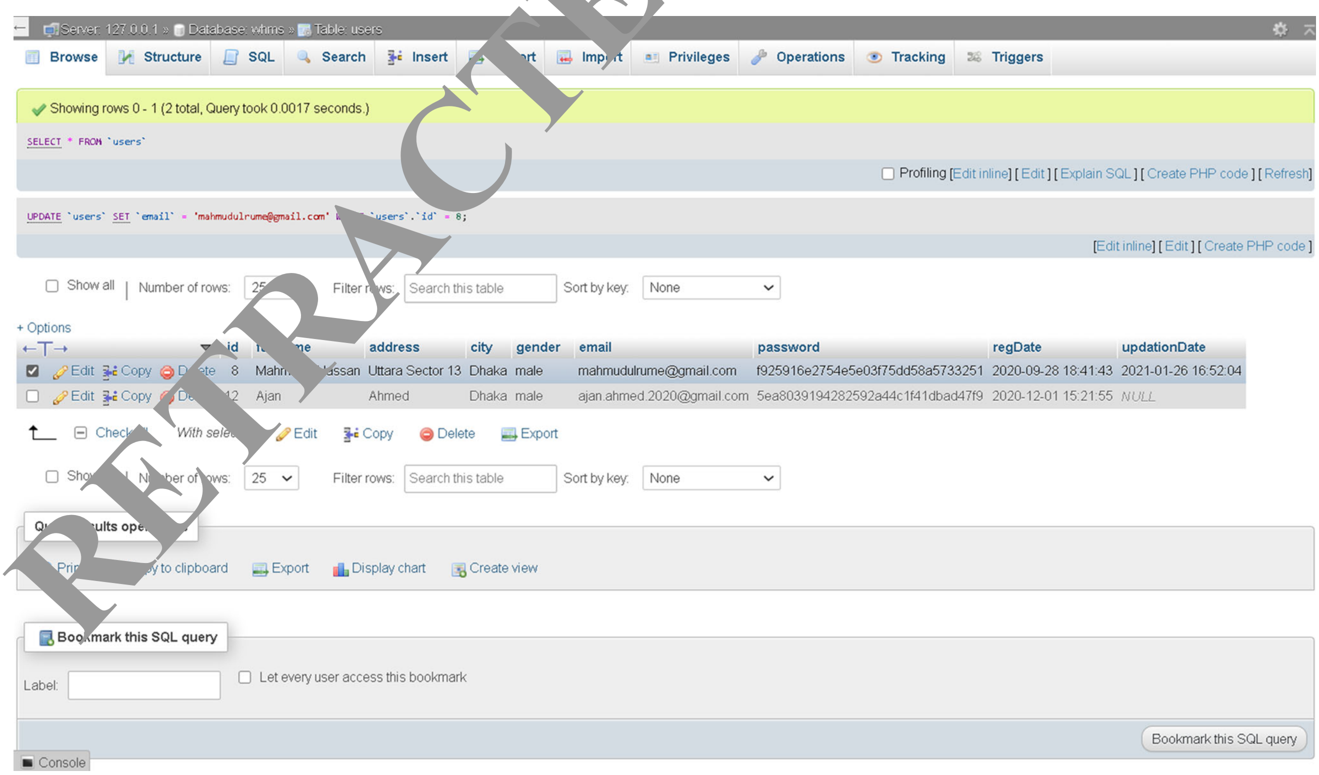


Fig. 20 Screenshot of the database updates of information provided by the user

Fig. 21 Screenshot of the website home page

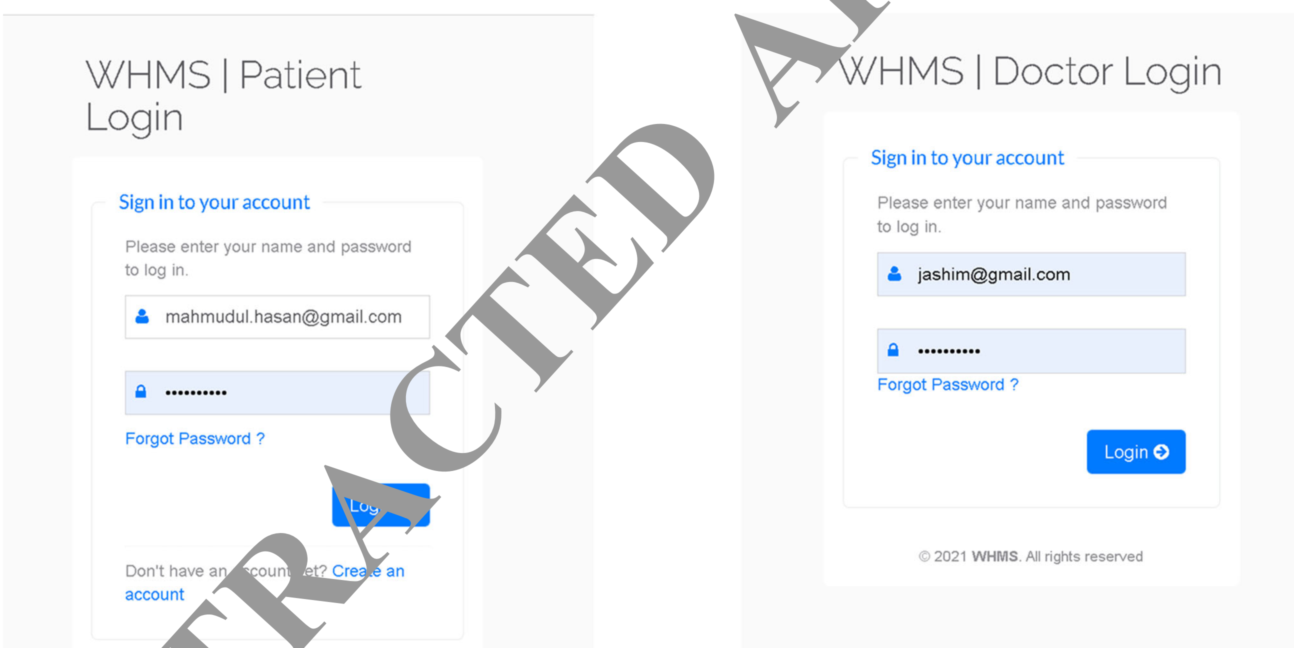


Fig. 22 Testing of website: **a** patient login/registration page, and **b** doctor login/registration page

and doctors do not have any accounts, they can create a new account, as can be seen in Fig. 22a-b.

The cloud benefit is utilized to display ECG graphically by calling information from the server and producing it from the Arduino code. In other parts, one can also make a live check of the persistent by utilizing a login username and secret word. The Internet front is shown within the taking after figuring at the side of the login page interface. Figure 21 appears on the domestic page that both specialists and patients see when they begin to visit the site. From there on, they can explore their particular entrances by logging in as a persistent or as a specialist, as shown in Fig. 22. Like their portable applications, they can either login or register.

The patients have a similar login interface on the website. Once inside, the doctors can view patient details by clicking on individual patients and adding prescriptions to them, as shown in the following figure. Once the prescription is uploaded by the doctor on the website, it can be seen via the database by the patient. Figure 23 shows a

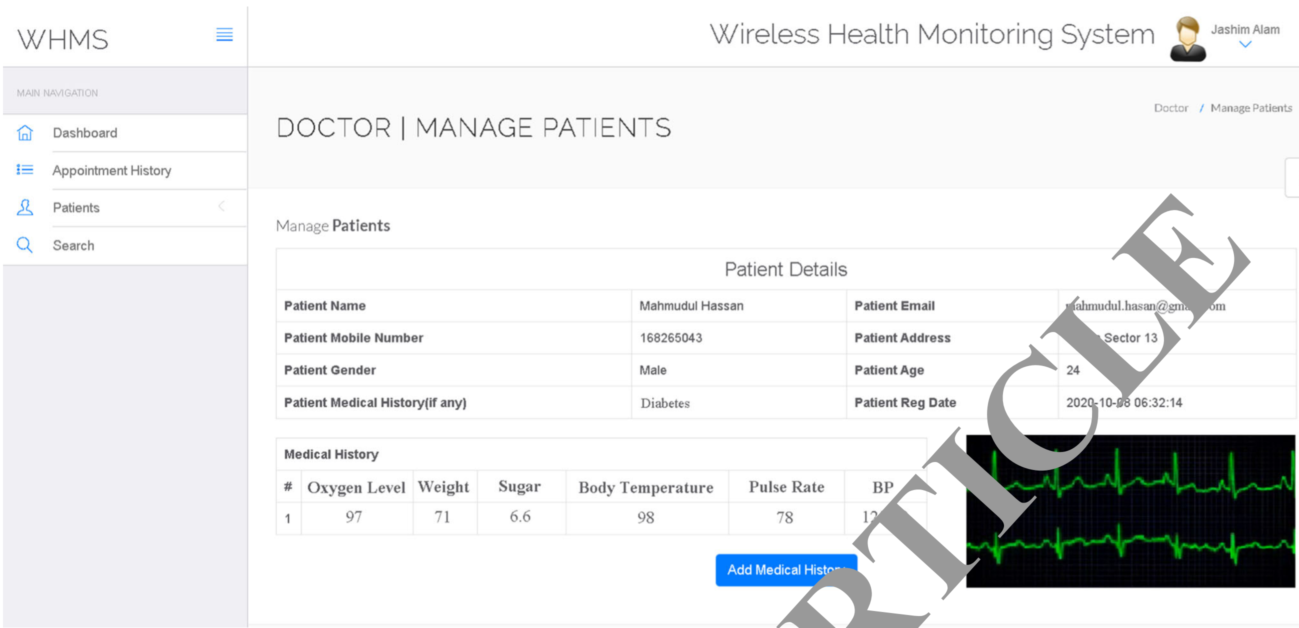


Fig. 23 Screenshots of the dashboard being used by the doctor

screenshot of the dashboard being used by the doctor. As seen in Fig. 23, the doctor can view all vitals, physiological parameters, and basic information of the patient directly from the website and then contact the patient in terms of prescriptions and medical check-ups required. On this website, doctors can monitor patients in real time. Doctors can attach and send a prescription to patients using this web platform, as shown in Fig. 18c. The presented work in this paper is novel, and it is shown throughout the paper.

Table 2 shows the comparison of the study presented in this article to the other published articles. From Table 2, it is noted that the presented work in this work is novel. This system is based on the IoT and a wide range of sensors integrated with it to measure vital physiological parameters of the human body. The proposed system has mobile and web applications for continuously monitoring the patients. This platform also includes a prescription service by the doctors so that patients can get the proper treatment plan remotely based on their physical condition. The available system in [6–8] is web-based telemedicine system where patients can discuss with doctors and get the prescription. The IoT-based patient monitoring system, on the other hand, is not available in [6–8]. The system proposed in [13] is IoT-based and has ECG and temperature sensors integrated with it. The measured data are directly sent to the web, but there is no mobile application and no prescription facilities available in this system. The number of sensors is limited in this [13], and it can only measure ECG and body temperature. The system proposed in [14] is an ECG monitoring system only, and the date can be seen on the mobile application. In this system [14], the measured ECG data are not sent to the web application and it does not include a real-time patient treatment plan. In [15], the authors have developed a mobile application and, using this system, patients can discuss with the doctors and get prescriptions. However, this system is not IoT-based and a real-time patient monitoring system is not integrated with this system. The systems in [16, 17] have limited sensors to measure physiological parameters of human bodies, and they do not have web applications integrated for real-time patient monitoring systems. Authors developed a web-based telemedicine system in [18] where doctor and patient can have discussion and patients can have treatment plan by the doctor. This system lacks the real-time IoT-based patient monitoring system integrated with it. From the above analysis and Table 2, it is noted that the proposed system in this study is novel compared to the work presented in the published paper. This proposed system is an IoT integrated telemedicine system with numerous sensors for vital physiological parameter monitoring of remote patients.

4 Conclusion

The primary objective of the proposed framework was to center on health monitoring with remote body range organizations. In any case, it effectively actualized the prototype of the physical machine and came up with an active construction of web- and app-based systems with a

Table 2 Comparison with other articles

Articles	Parameters measured	Mobile application	Web application	Prescription	IoT feature
This paper	Body temperature, heart rate, ECG, SpO2 levels, blood pressure, and blood glucose levels	Yes	Yes	Yes	Yes
Reference [6]	No	No	Yes	Yes	No
Reference [7]	No	No	Yes	Yes	No
Reference [8]	No	No	Yes	Yes	No
Reference [13]	ECG and temperature	No	No	No	No
Reference [14]	ECG monitoring system	Yes	No	No	Yes
Reference [15]	No	Yes	No	Yes	No
Reference [16]	Heart rate, SpO2, eye movement, temperature	No	No	No	No
Reference [17]	Heart Rate	Yes	No	No	Yes
Reference [18]	No	No	Yes	Yes	No

precise result investigation. Essentially, a remote body region organized could be an endless zone to expand. Executing computer science in therapeutic science has ended a modern period of development. Introducing a well-being checking framework with an application will truly be helpful to individuals in developing countries. One of the most thought processes of this system was to form a genuine time communication between doctor and patient in a simpler way. In spite of the fact that this model has been actualized and tried, a few more changes are required to present it in genuine life. Additional hardware is also required. The real objective of this framework will be satisfied when it can utilize the well-being checking framework and “wireless health monitor” application in genuine life, and individuals will benefit.

In general, IoT-based health care platforms that connect with smart sensors attached to the human body for health monitoring for daily check-ups are becoming more and more popular. In this paper, an IoT-based patient monitoring system was discussed and designed. Health care is one of the least funded sectors in Bangladesh and many other similar developing countries. There is no health coverage, and health insurance is almost non-existent. Thus, people living in rural and remote areas do not have access to proper health care, and when they do, it is too expensive. This research aimed to develop a real-time health monitoring system that is cheap, easy to use, and accessible by both doctors and patients. The wireless patient monitoring and care market is estimated to grow at a CAGR of 8.76% in the forecast period of 2020 to 2027, with factors like lack of health care industry professionals and unfavorable recompense policies acting as restraints to the growth of the market. Any person with non-communicable diseases will be an expected audience for the product, especially those living further away from hospitals. The paper’s main aim is to make health care management in developing countries better than that in the current system.

5 Future work

Since medical issues are being discussed, it would greatly benefit the application if measured sensor values could be improved. More research needs to be done in that particular area. The machine built could also be made wearable, which could be taken a look at. One further step would be to add an android app window for doctors as well. A special chat feature would benefit the website and Android applications a step further.

After sufficient research and development, it is recommended that the proposed system be deployed in remote houses for use in various places. The designed mobile and web applications, once fully developed, can be plugged into existing web domains of hospitals as a portal and can be launched as a fresh application for hospitals without existing domains. It is also recommended that new features such as a physiological data capturing device be incorporated into the current system.

We plan to extend our application beyond the Android platform to other IOS platforms for wide adaptability as a future direction. With the efficient technique presented in this paper, it is believed that this research can be extended to other areas of IoT, such as agriculture. Currently, we are working on doctors being able to send prescriptions to the pharmacist for the recommendation of dosage and possible dispensing of medications to patients. Finally, it would be of interest to carry out an evaluation of the overall performance of the proposed system using different mathematical and statistical evaluation tools.

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Availability of data and material Not applicable.

Declarations

Conflict of interest "The authors declare that they have no conflict of interest".

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