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DEVELOPMENT OF AN IOT-BASED AUTOMATIC REMOTE HEALTH MONITORING SYSTEM

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ABSTRACT

A well-planned health monitoring system is essential for the modern health center, and a portable remote health monitoring system with many intellectual features is becoming a great improvement in healthcare arrangements. The proposed system includes various micro-electronics medical devices and applications that come through network-connected devices and help to monitor patient's real-time medical data. In this paper, the patient's health condition has been monitored by using the four types of major health parameters, namely, temperature sensor, heart pulse rate sensor, blood pressure sensor module, and blood oxygen (SpO2) sensor. All the sensor nodes are connected to the Raspberry Pi-based embedded system. The real-time health data are recorded, stored, and transmitted to the doctor via the internet with the help of a Raspberry Pi-based embedded system and IoT server. The system will benefit the patient from remote areas with quick diagnosis, remote observation, home observation, and a medical data storage system.

Keywords: *Health monitoring, Raspberry Pi, embedded system, micro-electronics, health parameters, IoT server, remote observing.*

1. INTRODUCTION

Health is the root of all physical and mental happiness. In terms of Bangladesh, the number of doctors compared to patients is very inappreciable. A scientific modern smart medical system can solve this problem to some extent. A particular object can be included in the Internet of Things (IoT) if it establishes its communication system through a connection to the Internet (Gutte & Vadali, 2018). If the doctor can remotely monitor the patient's physical condition in real-time, the patient can recover to a large extent (Yeri & Shubhangi, 2020). This paper describes an IoT-based remote health monitoring system that can simultaneously measure body temperature, heart pulse rate, blood pressure, and blood oxygen (SpO2). It is very important to keep electronic health records (EHR) in a modern way for patient health diagnosis, which can be stored on its IoT server with the help of this system (Yeri & Shubhangi, 2020) (Kamarozaman & Awang, 2021). The basic health indicators of a human being are their body temperature, heart rate, blood pressure, and blood oxygen level. Body temperature refers to the heat of the body, where the body temperature of a healthy and a sick person must be different. A normal human's body temperature ranges from 97° Fahrenheit to 99° Fahrenheit (Khan *et al.*, 2021). Fluctuations in body heat and temperature occur due to fever and various physical ailments. The heart pulse rate is the number of heart beats per minute. A healthy person's heart rate fluctuates between 60 bpm to 100 bpm (Hameed *et al.*, 2020). Blood pressure is the pressure exerted by the blood on the blood vessels, which is one of the most important diagnostic attributes. Normal blood pressure for humans is considered to be between 90/60mmHg and 120/80mmHg (Chowdary *et al.*, 2018). If the blood pressure is higher than the ideal range, it is called hypertension and if the blood pressure is lower than the ideal range, it is called low blood pressure. The proportion of oxygen-saturated hemoglobin to all of the hemoglobin in the blood is known as oxygen saturation (SpO2). For most people, a typical pulse oximeter reading for oxygen saturation level ranges between 95% and 100% (Tamilselvi *et al.*, 2020). There are many procedures for measuring health conditions, analog or traditional and digital or sensor-based patient diagnosis. Currently, digital systems can provide more accurate values of health data that are more effective in case of patient diagnosis. Fig. 1 depicts the entire procedure in a block diagram.

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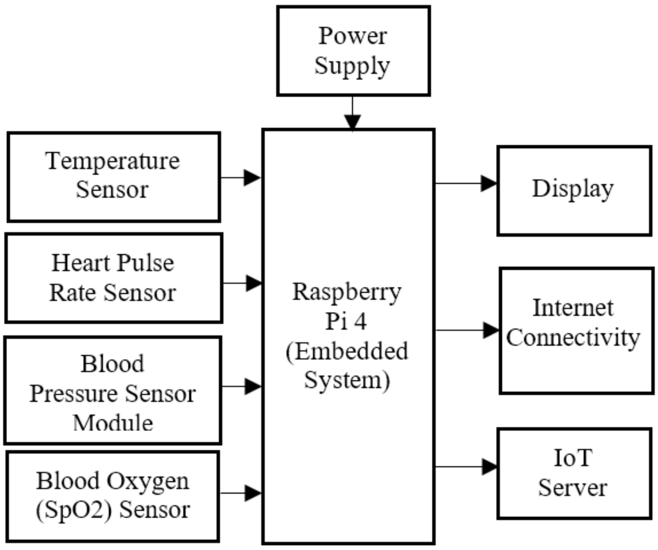

Figure 1: Block diagram of the proposed system.

2. RELATED WORK

IoT-based automated remote health monitoring has resulted in several notable advancements in medical science. The following describes the research in these areas.

Islam et al. (2020) developed a system for monitoring healthcare in an IoT context that can track fundamental patient characteristics like a heartbeat, body temperature, and CO2 sensors across an IoT-based network. The system employed the ESP32 as a connection to the processing device. They had a limitation not to use any direct display on their devices for viewing the monitored measuring offline. Misran et al. (2019) suggest that the aforementioned problems can be resolved by using LoRa sensors to monitor patients in the medical field. There are three phases suggested: collecting the patient's physical metrics from medical sensors, transmitting the data through LoRa sensors and a gateway, and uploading the data to the cloud for continued medical record processing. This system has been used to monitor diabetes and arterial hypertension, but because it cannot provide continuous medical information, analyzing ECG data is made more difficult.

Kazi et al. (2020) created a healthcare monitoring tool that comprises a wearable sensor node to track patient healthcare features and attributes and uses an internet connection to set up communication with doctors regarding the health situation. This worked only with heart rate data but it has a limitation of being a complex system which includes a base station with a wireless communication system. Anand et al. (2020) suggested the concept of delivering superior health care. Doctors utilize this information and deliver quick results from any location at any time after measuring it with the aid of a networked cloud by using Zigbee communication technology. When there is an emergency, the system notifies doctors by mail or text message of the patient's present state. Isla et al. proposed a smart healthcare system in an IoT environment to monitor the basic health signs of a patient. At the same time, they added the feature of monitoring the room condition in real-time. In their case, they used five sensors to measure the heartbeat and body temperature of the patient and also measured room temperature, CO density, and CO_2 density of the room. For each case, the error percentage was kept within the limit which was less than 5%. Anand et al. (2022) developed an SDN-based IoT device to overcome different real-life problems. SDN is used to decouple the control plane and data plane, but the command line interface and absence of doctors lead to the death of patients.

Bhardwaj et al. (2022) developed an IoT-based smart health monitoring system to monitor the heart rate, blood pressure, oxygen level, and body temperature of a person. However, they had slightly higher error levels compared to the proposed system. They had implemented a cloud platform to store the data which will help doctors to collect real-time data effortlessly, especially in the case of COVID-19 individual patients. The latest application in healthcare-monitoring systems by implementing the role of the IoT is explored by Abdulmalek et al. (2022). Nandi and Ahmad (2023) have used temperature sensors and heart pulse rate sensors to monitor major health parameters body temperature and heart rate of an individual. But nowadays, due to the increase in cost, demand for chip-less RFID sensors with IoT-based technology is increasing. Subrahmannian et al. (2022) provided a comprehensive review of chipless RFID sensors that play a vital role in cost-effective healthcare applications and focused on numerous chipless RFID sensors for IoT-based healthcare applications including their challenges and future directions.

The rest of the paper is organized as follows. The proposed model and details of it are introduced in section 3. Section 4 provides the system design and implementation of the proposed method. Section 5 includes the experimental result with the necessary table and diagrams and section 6 concludes the whole research work in addition to future works.

3. PROPOSED METHOD

Some sensor modules and microcontrollers are required to build a complete remote healthcare monitoring system. At the same time system, algorithm, and load balancing system controlled by the microcontroller make the whole invention come alive. A brief description of the hardware modules used is given below.

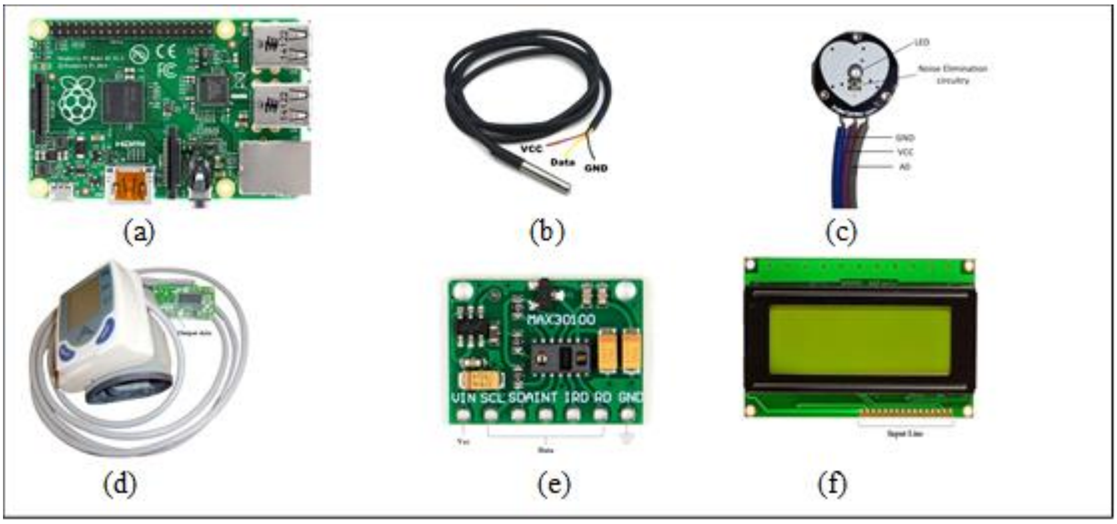

Figure 2: The hardware components for the healthcare monitoring system. (a) Raspberry Pi (b) temperature sensor (c) heart beat sensor (d) blood pressure sensor (e) blood oxygen sensor (f) LCD.

A. Raspberry Pi

The Raspberry Pi in Fig. 2(a) is a compact, affordable microcontroller that connects to a network and allows users to communicate with the technology. People of all ages can learn about computing and develop their programming skills in languages like Python and Scratch with the aid of this capable little device. It can play high-definition videos, browse the internet, make databases and Word documents, and operate as a server, among other computer-like functions. Moreover, the Raspberry Pi microcontroller can access a Wi-Fi network. With the TCP/IP protocol built-in, it is a self-contained SOC. It can either host an application or offload all Wi-Fi networking tasks to another application processor. It utilizes WiFi 802.11 b/g/n at 2.4 GHz and either WPA (Wi-Fi Protected Access) or WPA2 for security.

B. Temperature Sensor (DS18B20)

The digital temperature sensor DS18B20 in Fig. 2(b) operates according to a single wire protocol and has an accuracy of +-5% while measuring temperatures in the range of -67°F to +257°F or -55°C to +125°C. Data received through 1-wire might be between 9-bit and 12-bit in size. This sensor is connected to the microcontroller by a single wire and communicates the signal through one wire. It is an advanced quality protocol sensor programmed with a 64-bit serial code, enabling the operation of several sensors from a single microcontroller pin. In addition, the data line and power line of the sensor are identical for this it doesn't require additional power connections, which eliminates additional power consumption.

C. Heart Pulse Rate Sensor

In Fig. 2(c) optical heart pulse rate sensor measures pulse waves, which is capable of measuring differences in blood vessel volume due to the heartbeat. An optical sensor containing a green LED is used to detect heart pulse waves by measuring volume changes in blood vessels. An optical filter in the sensor module that is made for pulse wave identification filters out red and infrared rays from the environment. In wearables with low battery capacities, this results in prolonged operational times.

D. Blood Pressure Sensor Module

Blood pressure is the pressure exerted by the blood on the blood vessels. This blood pressure is produced by the heart through the blood circulation system. For measuring blood pressure, two types of measurements are simultaneously calculated, known as systolic and diastolic. The highest pressure during the heartbeat is called systolic blood pressure and the lowest pressure during the heartbeat is called diastolic. A blood pressure-measuring instrument is called a sphygmomanometer. The microcontroller-compatible sensor is developed by using an electrical circuit in conjunction with the blood pressure measuring device which can measure the blood pressure of the body and send the data to the microcontroller. Fig. 2(d) shows a blood pressure sensor module that works in conjunction with a microcontroller.

E. Blood Oxygen (SpO2) Sensor

The oxygen saturation of red blood cells is measured with a pulse oximeter sensor (SpO2 sensor). A pulse oximeter stimulates the fingertip with a low light beam and the light used by the pulse oximeter is red. The device can estimate the amount of oxygen in blood cells by flashing a light through the finger. Fig. 2(e) indicates the blood oxygen (SpO2) sensor.

F. LCD Display

Each character is shown in a 5x7 pixel matrix on the LCD in Fig. 2(f). This LCD has two registers, called Command and Data. This controller LCD for the HD44780 is typical. For Raspberry Pi and other microcontrollers, this display is ideally suited. It uses minimal power and features 8 data pins for I2C display connectivity.

4. SYSTEM DESIGN AND IMPLEMENTATION

The basic concept of the suggested system is the continuous online observation of patients and the room conditions of patients. As a result, the healthcare monitoring system makes use of three-stage architectural elements: sensor modules, data processing modules, and web user interfaces. The connected sensors are used to capture physiological data from the patient's body and the surrounding area. The Raspberry Pi microcontroller is used to process the acquired data before sending it to the gateway server. The pictorial interpretation and display of the collected results for the online user interface are done using the Thing Speak webserver. A variety of hardware parts are used to implement the system. During the implementation stage, every hardware component is put together. Using physical pins, all of the sensors are linked to the Raspberry Pi. Due to its integrated Wi-Fi module, the Raspberry Pi is being used as a processing system. For all sensors, the power source of the system comes from the power adapter and for emergency backup, a built-in battery is connected to the system. The signal pin for the heartbeat sensor is wired to the Raspberry Pi's GPIO1 physical pin. The temperature sensor's data pin is wired to the Raspberry Pi's GPIO2 pin. The Raspberry Pi's GPIO3 pin is connected to the data pin of the blood pressure module for use in monitoring the patient's blood pressure. For measuring blood oxygen in the execution, a SpO2 sensor is taken into consideration. The Raspberry Pi's GPIO4 pin is connected to the digital output pin of the SpO2 sensor. In the implementation part, all the components are joined together with the proper connection. The main microcontroller Raspberry Pi is the backbone of the system. All the components and sensors are connected to the Raspberry Pi controller. The body temperature sensor, heart pulse rate sensor, blood pressure sensor module, and blood oxygen sensor are connected as the input sensor of the microcontroller. The microcontroller processes the input analog signal and generates the digital output data. The decision-making system generates effective decisions inside the preprogrammed microcontroller. The output data are viewed in the local display unit and at the same time the data are ready to view for the remote monitoring system. Fig. 3. illustrates the working framework of the components.

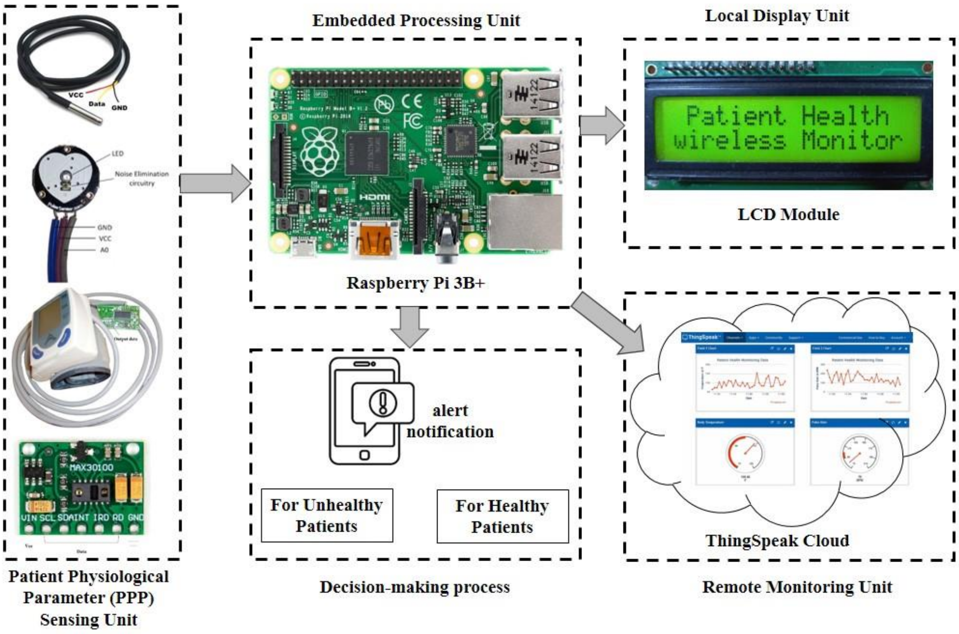

Figure 3: Working framework of the components.

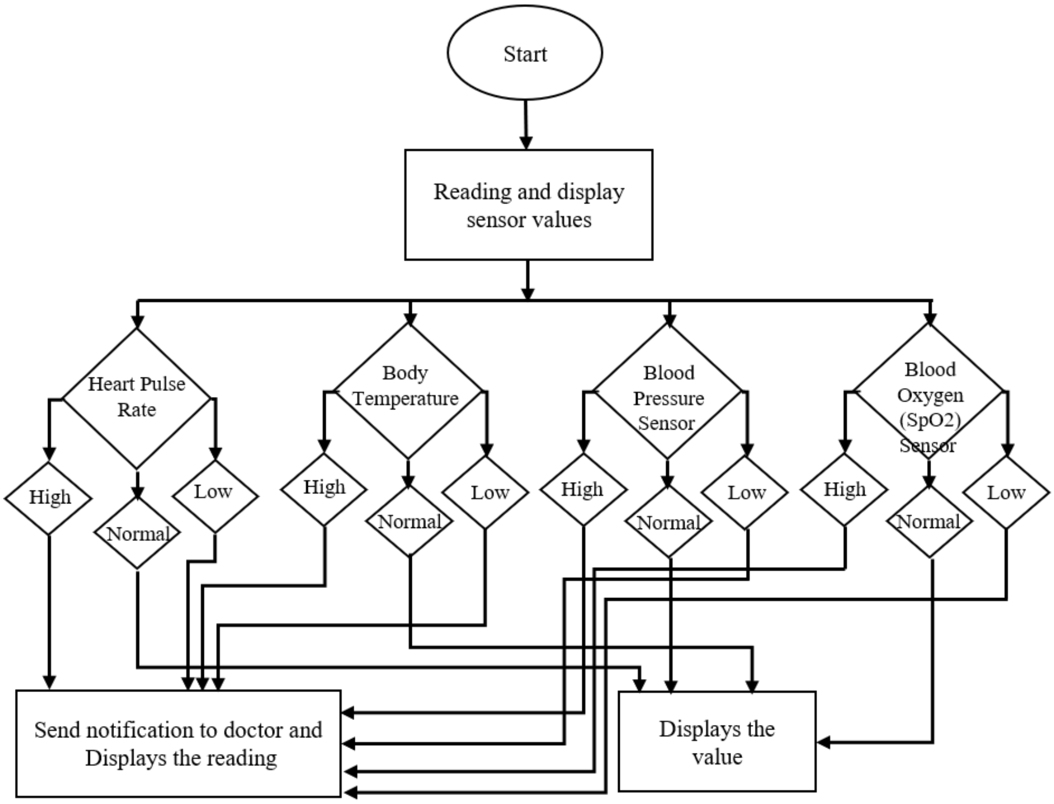

Figure 4: The working procedure of the developed system.

The Raspberry Pi is the central processing unit of the system, which will receive data from the various sensors and transmit it to a remote monitoring system or store it for later analysis. The temperature sensor, heart pulse rate sensor, blood pressure sensor, and blood oxygen sensor are connected to the Raspberry Pi via GPIO (General Purpose Input/Output) pins. The temperature sensor measures the body temperature of the patient and sends the data to the Raspberry Pi through the GPIO interface. The heart pulse rate sensor measures the heart rate of the patient and sends the data to the Raspberry Pi through a GPIO pin. The blood pressure sensor measures the blood pressure of the patient and sends the data to the Raspberry Pi through a GPIO pin. The blood oxygen sensor measures the oxygen level in the patient's blood and sends the data to the Raspberry Pi through a GPIO pin. The Raspberry Pi will use software to read data from each sensor, process it, and transmit it to a remote monitoring system or store it for later analysis. The system can also be configured to send alerts when certain thresholds are exceeded or when there are significant changes in the patient's health status.

In the flowchart, the first microcontroller is looking for sensor output data. Here the four types of sensors are wire connected to the microcontroller. When all the heart pulse rate sensors, body temperature, blood pressure sensors, and blood oxygen sensors send normal data to the microcontroller then the microcontroller simply displays the data. But when some of the parameters or all the parameters are sent abnormal data as higher or lower than normal value, then the preprogrammed microcontroller smartly sends the notification to the authorized medical crew. Fig. 4 illustrates the flowchart of the approach.

5. EXPERIMENTAL RESULTS

The created technique was put to the test on several subjects of varying ages under various circumstances for body temperature, heart rate, blood pressure, and blood oxygen saturation in the test instances. The pictorial view of our project is shown in Fig. 5. The produced system's real value and observed value were manually determined. We calculated the error rate based on the data to demonstrate the system's efficacy. Comparing the data collected by this system with actual data shows a success rate of more than 95 percent which increases the practicality of this system. Tables I, Table II, Table III, and Table IV show the actual and observed data with error rates for body temperature, heart rate, blood pressure, and blood oxygen sensors respectively.

Table 1: Heart Pulse rate data Authenticity

Subject	Observed (bpm)	Actual (bpm)	Error (%)
S1	69	70	1.43
S2	72	74	2.70
S3	75	76	1.31
S4	74	73	1.37
S5	76	78	2.56
S6	82	80	2.50

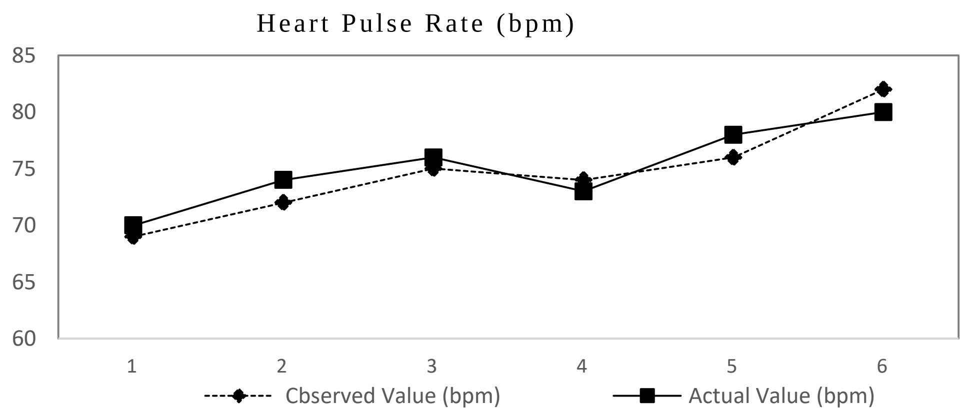

Figure 5: Heart pulse rate accuracy chart.

The body temperature readings collected from different individuals using both the experimental sensor and the supplementary mercury thermometer are shown in Table II and Fig. 5. By analyzing the data, the percentage difference in temperature readings between the two is computed which shows the deviation of experimental result from those of the mercury thermometer.

Table 2: Body Temperature data Authenticity

Subject	Observed (°F)	Actual (°F)	Error (%)
S1	97.9	97.5	0.41
S2	98.2	97.8	0.41
S3	97.6	97.7	0.10
S4	98.8	98.0	0.82
S5	97.4	97.6	0.20
S6	97.0	97.4	0.41

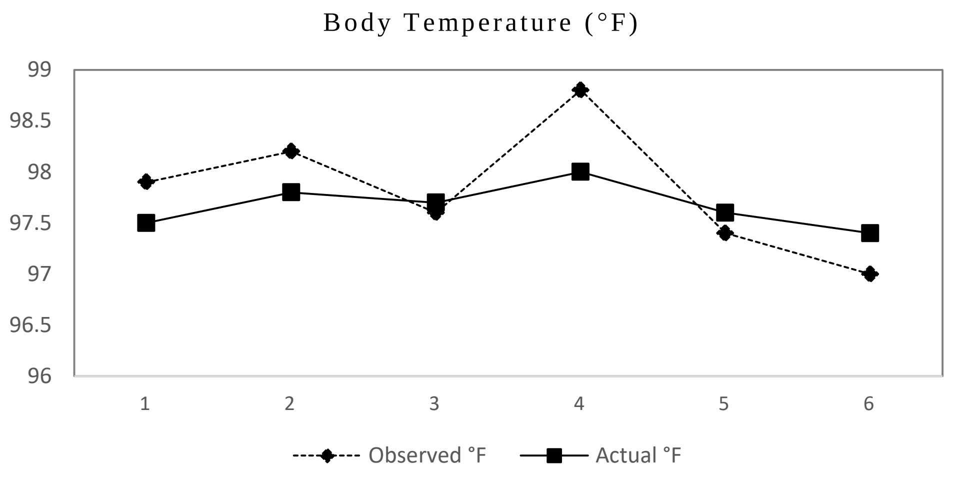

Figure 6: Body temperature accuracy chart.

The blood oxygen saturation data gathered from different individuals using an experimental spo2 sensor and the standard instrument are shown in Table 3 and Fig. 6. Using the data from the table and figure the error percentage of blood oxygen saturation readings is calculated which indicates the accuracy of the experimental sensor's reading compared to the established standard.

Table 3: Blood oxygen saturation data authenticity

Subject	Observed (°F)	Actual (°F)	Error (%)
S1	95	94	1.06
S2	94	92	2.17
S3	90	91	1.10
S4	97	95	2.11
S5	99	100	1.00
S6	102	101	0.99

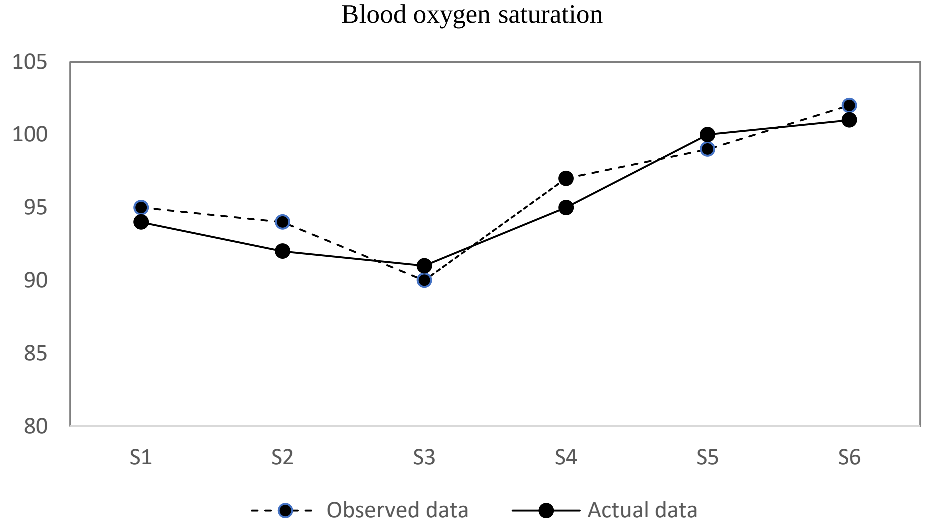

Figure 7: Blood oxygen saturation accuracy chart.

The blood pressure data collected from different persons are shown in Table IV. The results of the accuracy test for the designed system for systolic and diastolic data are shown in Fig. 7 and 8, respectively. The error percentage of blood pressure measurement is computed between this experimental blood pressure sensor module and the typical device.

Table 4: Blood Pressure Data Authenticity

Subject	Observed Data (mmHg)		Actual Data (mmHg)		Error (%)	
	Systolic	Diastolic	Systolic	Diastolic	Systolic	Diastolic
S1	110	75	105	76	4.76	1.31
S2	105	78	107	80	1.87	2.50
S3	120	80	115	78	4.35	2.56
S4	129	80	125	80	3.20	0
S5	100	82	102	79	1.96	3.79
S6	109	76	105	77	3.80	1.29

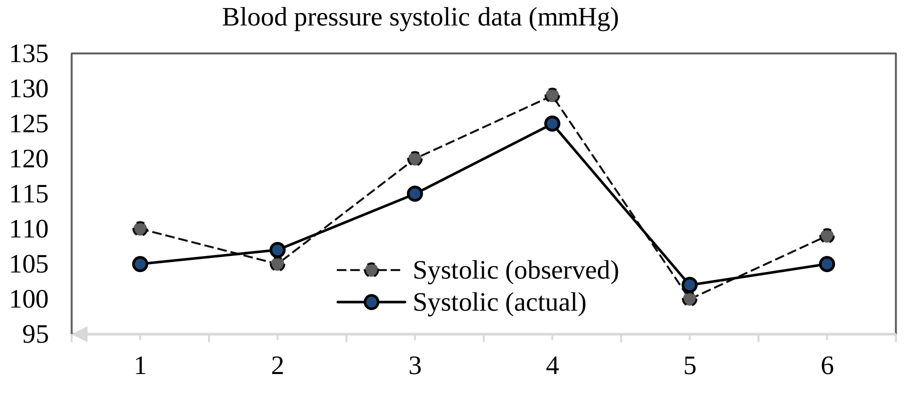

Figure 8: Blood pressure (systolic) accuracy chart.

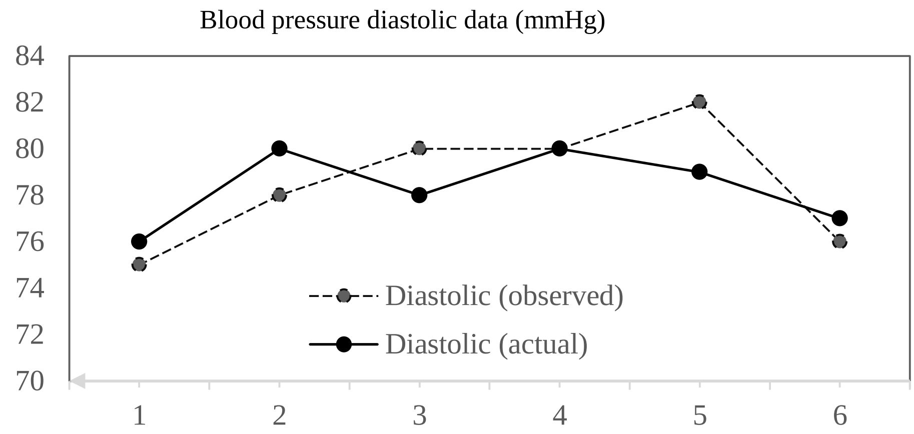

Figure 9: Blood pressure (diastolic) accuracy chart.

6. CONCLUSION

The computerized modern remote health monitoring system can be designed in such a way that can record, store, and transmit patient vital attributes such as heart rate, body temperature, blood pressure, and blood oxygen saturation to the corresponding concerned person. The accuracy rate of the sensor element is over 95% for all the environments. This system was very much applicable for treatment in home isolation in a pandemic situation. Authentic doctors and medical staff can access real-time patient's health data from any part of the world. The developed prototype was portable and easy to install for use. The proposed system will improve the current state of health care and can save many lives from death.

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