Design of a Cost-Effective Remote Health Monitoring System Using IoT

Subhadeep Paul[1], Madhusudan Maiti[2], Dibyendu Chowdhury[3], and Subhas Chandra Saha[1]

[1] Department of Electronics, Vidyasagar University, Midnapore, West Bengal, PIN Code - 721 102, India
subhadeeppaul191199@gmail.com, subhassaha@hotmail.com
[2] Department of Electronics and Communication Engineering, C. V. Raman Global University, Bhubaneswar, Odisha, PIN Code - 752 054, India
madhusudan.maiti@gmail.com
[3] Department of Electronics and Communication Engineering, Haldia Institute of Technology, Haldia, West Bengal, PIN Code - 721 657, India
dibyendu.chow@gmail.com

Abstract. An IoT-based health monitoring system is developed by which a patient at a remote location can be monitored 24×7 without any family member or health staff and updates the health data in real-time using the internet. The health monitoring system uses an Arduino board, a MAX30102 sensor, and a website. After attaching to a fingertip, the sensor senses the patient's body temperature and heart rate and sends that to the Arduino board for conversion to digital forms. Arduino board converts the health data to digital format and uploads the real-time data to a database. The website uses an authentication and authorization process to verify whether the user is valid. After proper validation, it shows health data on the website according to the role of the logged user. One can monitor a patient's health data with this device from anywhere in the world, having an internet connection.

Key words: IoT, Health monitoring, Remote access, Data security.

1 Introduction

The internet has become a part of our daily life as it is used almost everywhere to make our life smooth. The developments of mobile technology and communication network are the main reasons for this qualitative change. Now one can attend any function, ceremony, or meeting without being physically present in that place. This approach saves time and helps us connect with our loved ones from distant locations. However, a good internet connection is essential to perform such work.

The health condition of our family members is always a great matter of concern for us. Due to the recent advancement in mobile technology, we try to integrate medical facilities with the internet-based system to monitor patients' health conditions seamlessly. The Internet of Things (IoT) helps us to create the environment easily. The IoT [1] is an interconnected network with physical devices, sensors, processing devices, and application software. An IoT-based health monitoring system can track a patient's medical data and conveys the information to doctors and/or family members. This way, a doctor analysing the incoming medical data understands the patient's condition and takes necessary action. Doctors do not have to visit a patient place when a patient needs a checkup, so the time for travelling can be used to monitor other patients. This could eventually increase the productivity of the current healthcare system. Also, at the same time, family members maintaining their normal duties can track the health status of their loved ones at a distant place without a health staff.

As in the COVID-19 pandemic, it has been observed how people suffered for not having a proper remote monitoring system because, in an epidemic like COVID-19, no family member was allowed to stay with a patient due to its highly infectious nature. In this kind of situation, a remote monitoring system can detect the health condition and possible threats to the patient's life. This information helps to save the patient's life. Doctors do not have to be in close contact with the infected person. So, the safety of healthcare workers will be increased, which was one of the significant drawbacks at the initial stage of COVID-19. Family members do not have to call the hospital when they need to know about the patient's health status; they can login to a mobile application and see the situation in real-time. The COVID-19 pandemic helps us to understand the necessity of remote monitoring systems.

Paganelli et al. [2] designed an IoT-based early-warning architecture using a wearable kit for health monitoring and a data analysis algorithm for prediction and decision-making. It also consists of the machine learning algorithm, which sends an early alert for any emergency depending on previously trained data. Filho et al. [3] developed a remote healthcare platform to monitor ICU patients during the COVID-19 pandemic. The sensors attached to the patient's body provide information about ECG, blood pressure and glucose, heart rate, oxygen saturation, temperature, breathing rate, and capnography. The environment sensors provide information about environment temperature, location with latitude and longitude, and humidity. It helps to detect if any emergency condition for patients arises. A health monitoring system was created by Islam et al. [4] to monitor heart rate, body temperature, and environment in a hospital room: viz. humidity and gas concentrations of CO and CO_2, and healthcare professionals who are concerned can check the health data instantaneously. Rahaman et al. [5] wrote a review of IoT devices used in healthcare and remote monitoring. This demonstrates the advantages of employing IoT devices for health monitoring and their potential. Using Digital twin technology, Liu et al. [6] developed a cloud-based health monitoring system for older people. Karantonis et al. [7] presented a real-time human movement and posture detection system for detecting functional ability and activity levels. They use a waist-mounted 3-axis accelerometer sensor for this system and acquire a high level of accuracy. Thilakanathan et al. [8] developed a system where a patient connects sensors to his/her body and seeds health data periodically to a web server (cloud-based storage) through a mobile application using a secure server. Tripathi et al. [9] made a system with wearable devices to detect patients' health conditions. Hossaina et al. [10] gave a brief review of some recently developed health monitoring systems. They concluded about how this IoT-based technology and interconnect device can improve the healthcare system. Banerjee et al. [11] created a heart rate detector using the Photoplethysmography concept with an IR LED and photodiode as the fundamental sensors. Gregoski et al. [12] reported a system for monitoring heart rate employing mobile light and a camera. Oresko et al. [13] designed a cardiovascular disease (CVD) detection system. An interconnected mobile product was developed by Trivedi et al. [14] to monitor body temperature and heartbeat continuously.

In this paper, we report the development of a cost-effective, reliable, and continuous IoT-based health monitoring system consisting of an Arduino board, MAX30102 sensor, and a website to provide the best healthcare facilities to the people of rural areas. We have significantly improved our system in comparison with the preexisting technologies. While [13] can only display the health data in the measuring device and cannot send data to the cloud for remote health monitoring, our proposed device can send health data to a cloud-based database for remote access. [9], [12], [14] are not suitable for measuring health data continuously, whereas our device can be used in real-time. Our developed system is not dependent on any particular device like a smartphone or smartwatch, so it is more cost-effective than [4], [8], [11], [12] and is more efficient for implementing in the rural area. Also, our website can be accessed through any device connected to the internet. Our device is very compact, and unlike [3], this device can be used as a mobile health monitoring unit only with a proper internet connection. Also, the device is simple to install and operate.

2 Methodology

The developed system consists of three modules: a sensing module, a processing module, and an interaction module. Fig. 1 shows the functional flow diagram of the developed system and the interconnection between all three modules. The details description of these modules is described in later this section. Fig. 2 shows the architectural flow diagram of the system.

The sensing module consists of sensors that collect health data from a patient and converts to digital form by processing the raw data. Then the digital data are transmitted to the processing module for further processing. The sensing module has two components: (i) MAX30102 sensor and (ii) Arduino UNO SMD R3. The MAX30102 senses the raw data and sends that to Arduino UNO which collects the data converts that to digital form and transmits that to a processing unit. The circuit diagram for interfacing the MAX30102 sensor with Arduino is shown in Fig. 3.

The processing module gathers patient details and integrates that with the digital data transmitted from the sensing module for a particular patient. Then

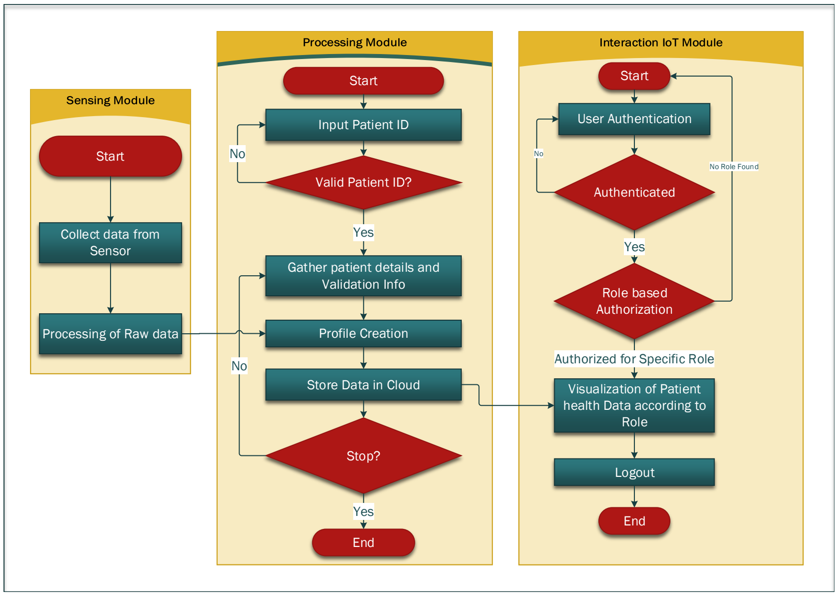


Fig. 1. Functional flow diagram of the system.

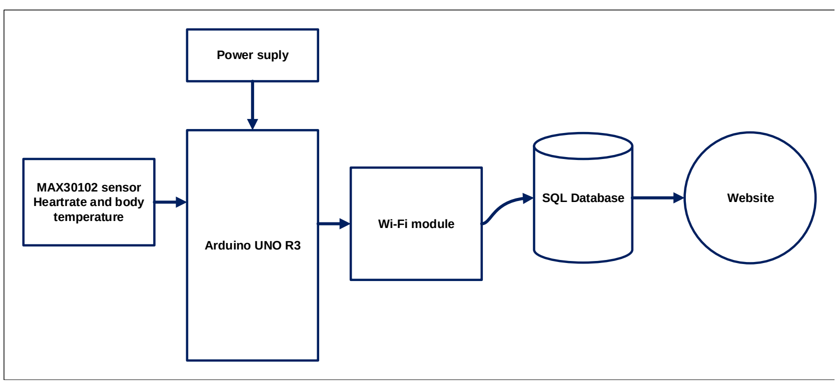


Fig. 2. Architectural flow diagram of the system.

it stores the data in cloud-based storage and allows the interaction module to share with authenticated and authorized users.

The interaction module is an IoT-based software that authenticates the user identity and authorizes the user's specific role. After completing this process, it will show the patient health data to the user. The authorization process will be the controller of the data one user can see, depending on his/her role.

In our present work, the sensing module is the hardware, and the processing and interaction module are the software. The processing module consists of a Database and a Backend server. The interaction module is a website and backend

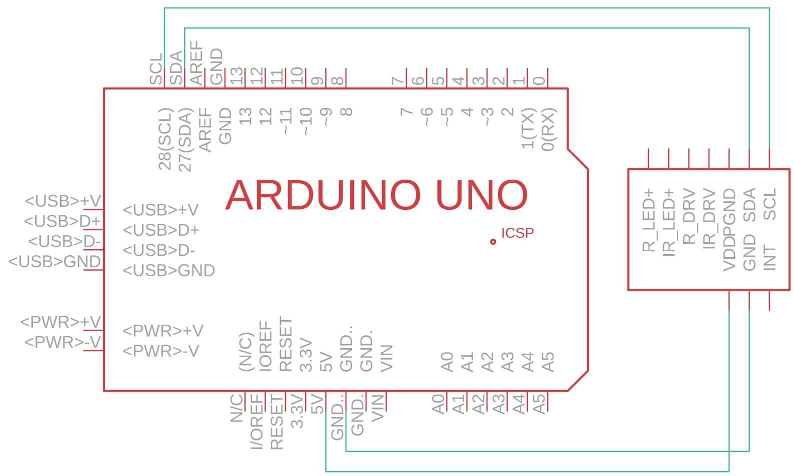


Fig. 3. The circuit diagram for interfacing MAX30102 with Arduino UNO.

authentication process, that displays the health data using role-based authentication. It is designed for two types of roles for authentication – (i) Admin: has the privilege to view all patients data, update any parameter, and delete any patient details. (ii) User: can only view his/her patient details and health data.

2.1 Heart rate measurement using MAX30102

The Fig. 4 shows the setup to measure a patient's heart rate (HR). The MAX30102 sensor glows both the lights of IR and Red LEDs through the skin of a fingertip and measures the reflected light with a photodetector. The output waveforms of the photodetector are shown in Fig. 5. To determine HR, the enlarged output profile as detected with IR LED is shown in Fig. 6.

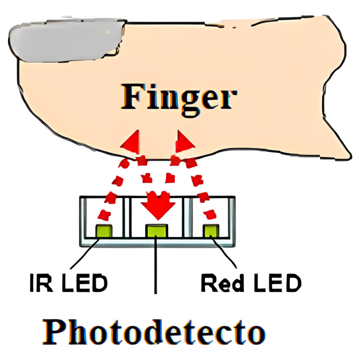


Fig. 4. A setup with MAX30102 sensor for heart rate measurement.

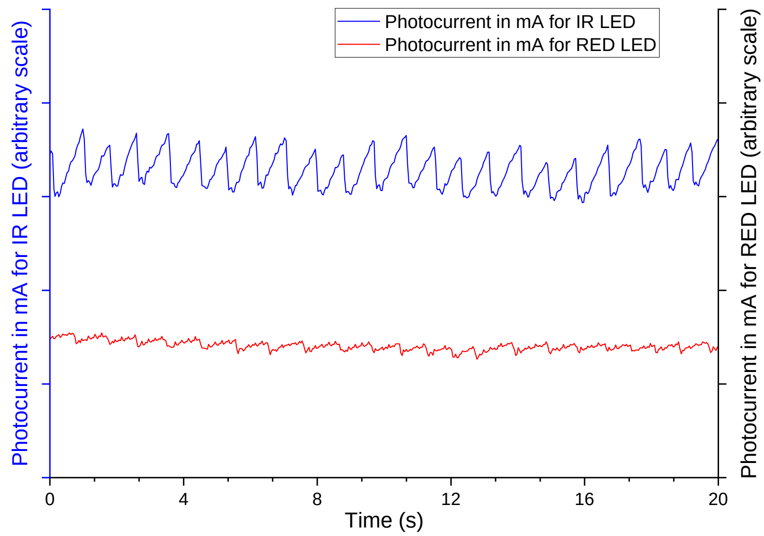


Fig. 5. Output waveforms of the photodetector.

We first calculate the time difference (t) in second of two consecutive beats in Fig. 6. Then HR in beats per minute (BPM) is given by the equation 1,

$$BPM = 60/t \tag{1}$$

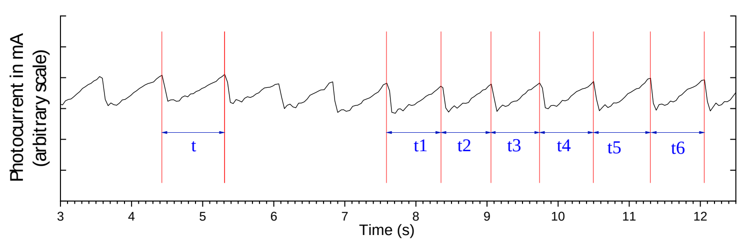


Fig. 6. An enlarged output profile of IR LED.

As the time difference between two beats is very small and not always constant, the BPM value changes significantly for a slight variation in time difference. To overcome this problem, we take a few consecutive values of BPM and calculate their average. In this way, we get an average HR in BPM. So, every time we get an HR value is the average of the last few HR values. We can take different numbers of observed values for the standard in our requirement. For six consecutive BPM data, as shown in Fig. 6, the average BPM will be,

$$Avg.\ BPM = \frac{1}{6}\sum_{i=1}^{6} BPM_i$$
$$\text{where,} \quad BPM_i = \frac{60}{t_i} \qquad (i = 1\ to\ 6) \tag{2}$$

2.2 Temperature measurement using MAX30102

For measuring body temperature, we used the on-chip temperature sensor of MAX30102, which stores the temperature data on the first in first out (FIFO) buffer.

3 Results and discussion

The HR was determined using the developed system with six consecutive BPM data, and that was also measured manually. Figure 7 and Table 1 represent the results of the HR measurements of 30 patients. It is evident from Table 1 that the HR measured by the system is matched well with that obtained manually. Primarily the percentage error was noted as 0-4.5% taking four consecutive BPM data and that taken manually by an ordinary person. Considering six consecutive BPM for average HR and measuring the manual HR with professional health care personnel, the error decreases to 0-2.5% range. The reasons for improvement in accuracy on HR measurement are taking 6 BPM average and measuring HR with professional healthcare personnel.

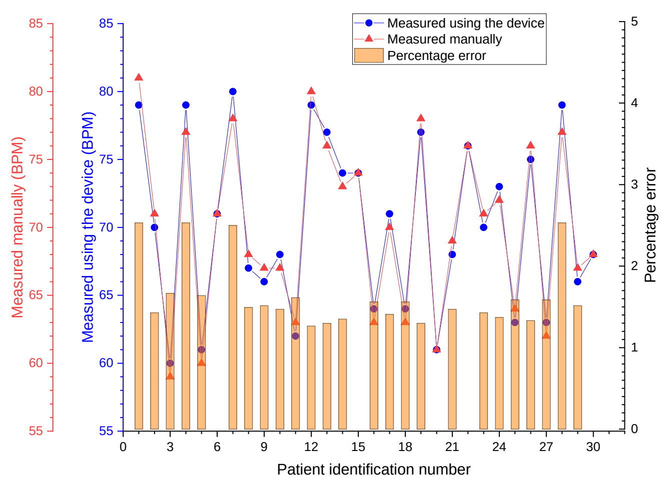


Fig. 7. Graphical representation of heart rate measurements.

Table 1. Results of heart rate measurements.

Patient identification number	Measured using the device in BPM	Measured manually in BPM	Percentage error (%)
1	79	81	2.5
2	70	71	1.4
3	60	59	1.7
4	79	77	2.5
5	61	60	1.6
6	71	71	0.0
7	80	78	2.5
8	67	68	1.5
9	66	67	1.5
10	68	67	1.5
11	62	63	1.6
12	79	80	1.3
13	77	76	1.3
14	74	73	1.4
15	74	74	0.0
16	64	63	1.6
17	71	70	1.4
18	64	63	1.6
19	77	78	1.3
20	61	61	0.0
21	68	69	1.5
22	76	76	0.0
23	70	71	1.4
24	73	72	1.4
25	63	64	1.6
26	75	76	1.3
27	63	62	1.6
28	79	77	2.5
29	66	67	1.5
30	68	68	0.0

Oxygen is delivered from the lungs to every cell of the body by the hemoglobin in the blood. When hemoglobin contains oxygen, it forms an unstable, reversible bond with oxygen, and it is called oxyhemoglobin $[Hb(O_2)_4]$. Oxyhemoglobin is bright red in colour. The form of hemoglobin without oxygen or oxygen unbounded form is called deoxyhemoglobin which is purple in colour. Due to the colour difference, the oxyhemoglobin in the arterial blood absorbs more IR light than that by the deoxyhemoglobin. Each time the heart beats, blood is pumped into the finger, altering the quantity of light that is reflected (Fig. 4) and resulting in a change in the waveform of the photodetector (Fig. 5). A slight shift in HR measurement done by the developed system and manual observation is due to the behaviour of the photodetector.

The body temperatures of 30 patients were measured with our system as well with a thermometer by a professional health care personnel, are displayed in

Table 2. Body temperature measurement results.

Patient identification number	Measured using the device in °F	Measured using a thermometer in °F	Percentage error (%)
1	97	96.7	0.31
2	99	98.4	0.61
3	97	97.2	0.21
4	99	99.7	0.71
5	98	98.3	0.31
6	100	100.7	0.70
7	98	98.5	0.51
8	100	99.6	0.40
9	102	102.1	0.10
10	98	97.3	0.71
11	102	102	0.00
12	101	100.8	0.20
13	99	99.1	0.10
14	102	102	0.00
15	98	98.7	0.71
16	99	98.3	0.71
17	98	97.4	0.61
18	101	101.3	0.30
19	98	98.1	0.10
20	99	98.9	0.10
21	100	100.7	0.70
22	98	98.2	0.20
23	102	102.1	0.10
24	99	98.9	0.10
25	98	98.7	0.71
26	99	99.7	0.71
27	100	99.2	0.80
28	98	98.5	0.51
29	98	98.7	0.71
30	101	100.4	0.59

Table 2 and Fig. 8. It is noted that the error in measuring body temperature lies 0-0.8%. The body temperature was measured with the developed system and by an ordinary person, and the maximum error was detected within 1%. Comparing Fig. 7 with Fig. 8, it may infer that the body temperature measurement by the device is more accurate than the HR measurement. It is primarily due to the better response of the on-chip temperature sensor than that of the photodetector.

The observed results are displayed on our developed website. The health data from the Arduino board are uploaded to the database using Wi-Fi, and that can be accessed through our developed website. The website has two types of login options: one is Admin login, and another is user login. When someone

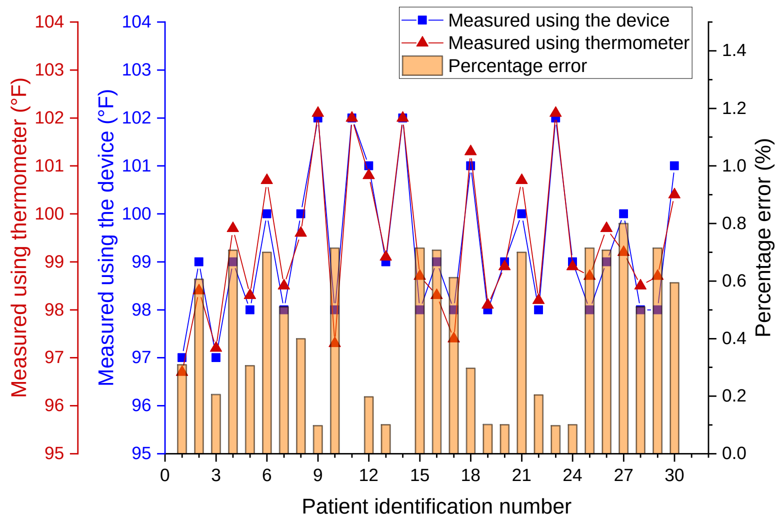
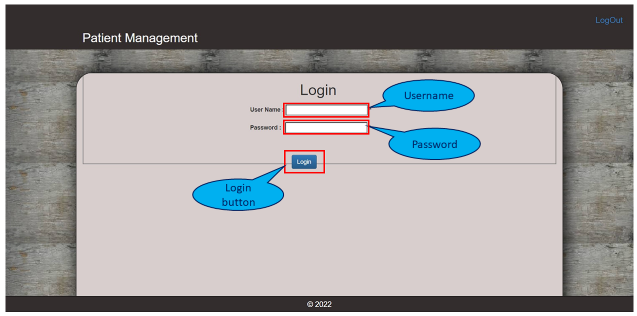


Fig. 8. Graphical representation for body temperature measurement results.

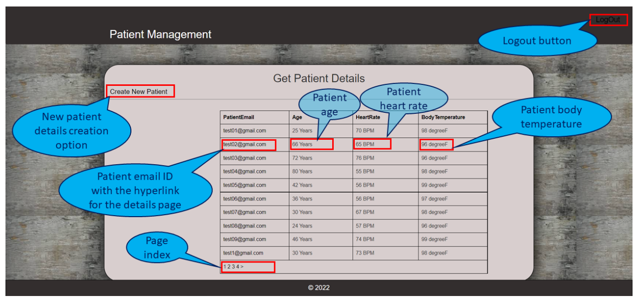
login through user login credentials, he/she will get access to only read his/her patient's health details. On the other hand, by logging through Admin login credentials, one can view all the patients health details and have access to create a new patient's profile and update or delete any patient details. Some snapshots of the developed website with functionalities are shown in Fig. 9. Figure 9(a) shows the functionalities of the login page. Different functions of the admin dashboard are described in Fig. 9(b). In Fig. 9(c) the patient details page from admin panel is elaborated. The Fig. 9(d) displays the patient dashboard with the functionalities.

4 Future work

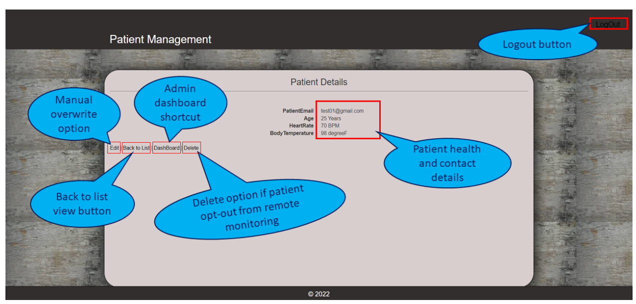
Although the current device is reliable for measuring two important health parameters: heart rate and body temperature of a patient, sometimes more than these two health parameters are to be known. So, this work will be extended further to measure other health parameters namely SpO_2 (Saturation of Peripheral Oxygen), ECG (Electrocardiogram), and Blood pressure and environmental data like humidity, room temperature, $PM_{2.5}$ (Particulate matter under 2.5 microns in size), PM_{10} (Particulate matter under 10 microns in size), CO_2 and CO levels. Also, we are planning to integrate an email notification to the patient and healthcare staff with the website upgradation.



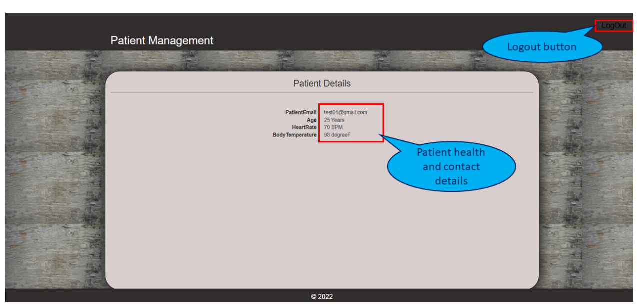
(a) Login page of the website.



(b) Admin dashboard with all patient details.



(c) Admin panel with edit and delete options for any patient.



(d) Patient dashboard from the website.

Fig. 9. Different web pages of our developed website.

5 Conclusion

The remote health monitoring system is reliable for remotely measuring heart rate and body temperature. It can be used for monitoring any patient. The sensor senses body temperature and heartbeat and uploads that to the database, which can be accessed wirelessly through the website. One can access data from anywhere in the world with an internet connection. The authentication and authorization processes help to keep the data securely in the database. So there is no risk of leaking personal data or the patient's health data. Overall the system created a secure connection between the sensing device and the observer (Patient party/doctor/administrator) by which an observer can track health data 24×7. By continuously monitoring health conditions, we can detect if any emergency medical situation is created for a patient. This helps us to take quick action on any medical emergency. The device is very cost-effective and made to support the rural people of our country. Ease of setup and reusability are the main advantages of our device. There ate future scopes to measure other health and environmental parameters for proper monitoring of a patient and for website upgradation.

References

1. International Telecommunications Union – Telecommunications Sector: IUT-T, https://www.itu.int/en/ITU-T/gsi/iot/Pages/default.aspx, last accessed 2022/11/15.
2. Paganelli, A.I., Velmovitsky, P.E., Miranda, P., Branco, A., Alencar, P., Cowan, D., Endler, M., Morita, P.P.: A conceptual IoT-based early-warning architecture for remote monitoring of COVID-19 patients in wards and at home. Internet of Things. 18, 100399 (2022). https://doi.org/10.1016/j.iot.2021.100399.
3. Filho, I. de M.B., Aquino, G., Malaquias, R.S., Girao, G., Melo, S.R.M.: An IoT-Based Healthcare Platform for Patients in ICU Beds During the COVID-19 Outbreak. IEEE Access. 9, 27262–27277 (2021). https://doi.org/10.1109/access.2021.3058448.
4. Islam, Md. M., Rahaman, A., Islam, Md. R.: Development of Smart Healthcare Monitoring System in IoT Environment. SN Computer Science. 1, (2020). https://doi.org/10.1007/s42979-020-00195-y.
5. Rahaman, A., Islam, Md., Islam, Md., Sadi, M., Nooruddin, S.: Developing IoT Based Smart Health Monitoring Systems: A Review. Revue d'Intelligence Artificielle. 33, 435–440 (2019). https://doi.org/10.18280/ria.330605.
6. Liu, Y., Zhang, L., Yang, Y., Zhou, L., Ren, L., Wang, F., Liu, R., Pang, Z., Deen, M.J.: A Novel Cloud-Based Framework for the Elderly Healthcare Services Using Digital Twin. IEEE Access. 7, 49088–49101 (2019). https://doi.org/10.1109/access.2019.2909828.
7. Karantonis, D.M., Narayanan, M.R., Mathie, M., Lovell, N.H., Celler, B.G.: Implementation of a Real-Time Human Movement Classifier Using a Triaxial Accelerometer for Ambulatory Monitoring. IEEE Transactions on Information Technology in Biomedicine. 10, 156–167 (2006). https://doi.org/10.1109/titb.2005.856864.

8. Thilakanathan, D., Chen, S., Nepal, S., Calvo, R., Alem, L.: A platform for secure mon-itoring and sharing of generic health data in the Cloud. Future Generation Computer Systems. 35, 102–113 (2014). https://doi.org/10.1016/j.future.2013.09.011.
9. Tripathi, V., Shakeel, F.: Monitoring Health Care System Using Internet of Things - An Immaculate Pairing. 2017 International Conference on Next Generation Computing and Information Systems (ICNGCIS). (2017). https://doi.org/10.1109/icngcis.2017.26.
10. Hossain, M.S., Muhammad, G.: Cloud-assisted Industrial Internet of Things (IIoT) – Enabled framework for health monitoring. Computer Networks. 101, 192–202 (2016). https://doi.org/10.1016/j.comnet.2016.01.009.
11. Banerjee, S., Roy, S.: DESIGN OF A PHOTOPLETHYSMOGRAPHY BASED PULSE RATE DETECTOR. International Journal of Recent Trends in Engineering & Research (IJRTER). 02, 302–306 (2016).
12. Gregoski, M.J., Mueller, M., Vertegel, A., Shaporev, A., Jackson, B.B., Frenzel, R.M., Sprehn, S.M., Treiber, F.A.: Development and Validation of a Smartphone Heart Rate Acquisition Application for Health Promotion and Wellness Telehealth Applications. International Journal of Telemedicine and Applications. 2012, 1–7 (2012). https://doi.org/10.1155/2012/696324.
13. Oresko, J.J., Jin, Z., Cheng, J., Huang, S., Sun, Y., Duschl, H., Cheng, A.C.: A Wearable Smartphone-Based Platform for Real-Time Cardiovascular Disease Detection Via Electrocardiogram Processing. IEEE Transactions on Information Technology in Biomedicine. 14, 734–740 (2010). https://doi.org/10.1109/titb.2010.2047865.
14. Trivedi, S., Cheeran, Alice.N.: Android based health parameter monitoring. 2017 International Conference on Intelligent Computing and Control Systems (ICICCS). (2017). https://doi.org/10.1109/iccons.2017.8250646.