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ORIGINAL RESEARCH

IoT-Based Smart Health Monitoring System for COVID-19

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Abstract

With the commencement of the COVID-19 pandemic, social distancing and quarantine are becoming essential practices in the world. IoT health monitoring systems prevent frequent visits to doctors and meetings between patients and medical professionals. However, many individuals require regular health monitoring and observation through medical staff. In this proposed work, we have taken advantage of the technology to make patients life easier for earlier diagnosis and treatment. A smart health monitoring system is being developed using Internet of Things (IoT) technology which is capable of monitoring blood pressure, heart rate, oxygen level, and temperature of a person. This system is helpful for rural areas or villages where nearby clinics can be in touch with city hospitals about their patient health conditions. However, if any changes occur in a patient's health based on standard values, then the IoT system will alert the physician or doctor accordingly. The maximum relative error ($\%\epsilon_r$) in the measurement of heart rate, patient body temperature and SPO_2 was found to be 2.89%, 3.03%, 1.05%, respectively, which was comparable to the commercials health monitoring system. This health monitoring system based on IoT helps out doctors to collect real-time data effortlessly. The availability of high-speed internet allows the system to monitor the parameters at regular intervals. Furthermore, the cloud platform allows data storage so that previous measurements could be retrieved in the near future. This system would help in identifying and early treatment of COVID-19 individual patients.

Keywords IoT · Health monitoring · Sensor interfacing · Raspberry Pi · Cloud platform

Introduction

The spread of the COVID-19 pandemic around the world has changed and influenced the daily life of individuals largely. The slow production and delayed distribution of vaccines have put up much stress on the health system of developing and developed countries. The COVID-19 has reduced the % GDP of most of the countries drastically. So, bringing back the GDP to a higher level is of prime concern as it depends upon the recovery of the population also. Although collaborative efforts have been taken by most of the country from developing, deploying the vaccine up to sanitization has helped the world economy recover at a smooth rate [1]. Also, removing the restrictions could trigger another wave and further mutation can't be ruled out as observed in the recent mutated Omicron virus [2]. Thus, monitoring of COVID-19 infected and recovered patients in the wards is of great concern for the health authorities/departments. So the diagnosis and prevention of COVID-19 could be made with the support of sensor technology integration with IoT embedded with machine learning algorithm for processing of big data of patients [3]. It was observed that in the winter season, the infection rate of COVID-19 increases, as the conditions for the survival of SARS-CoV-2 virus is much favourable [4]. Internet of things is one of the emerging technologies that is being incorporated in every part of human life. The most common usage of IOT is in the smart home, automated industries, schools, oil refineries, environment monitoring systems, smart cities etc. The challenge of COVID-19 can be reduced by utilizing the internet of things (IoT) based smart health monitoring system. This may be wearable similar to smart watch or could be embedded in the bed of the COVID-19 patients. Biomedical signals can provide information about an individual's health, so much

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information could be gathered, and necessary inference could be drawn out of observation. The various biomedical signals that could be sensed to detect the COVID-19 includes heart rate, SPO_2, CO_2, temperature, blood pressure, etc. Machine learning techniques could be deployed to identify the COVID-19 patients out of a large amount of data through measuring the health parameters, storing on the cloud with the help of IoT. The integration of machine learning with IoT is going to be advantageous in many ways. IoT technology would help the health authorities segregate the patients who require immediate treatment and few others that could be home quarantined, thus preventing the giant patient bubble at the hospital/ community health centres. The IoT-based smart health monitoring system could reduce the requirement of O_2 in hospitals. This system could also be integrated with GPS chip to track the recovered patient location. As the lockdown has opened in most countries, individuals in the offices, hotels, educational institutes are physically in contact, thus increasing the chance of COVID-19 infections and moving toward the 3rd wave of the pandemic. So, in such a scenario, data of the individuals is shared with the health authorities, and the possible infected persons could be quarantined promptly.

An automated health monitoring system is to be developed that reacts or creates an alarm in the critical situation of the patient. The data are analyzed through Node MCU microcontroller to send messages via email and twitter to the doctors and concerned people. Additionally, it also records and maintains the earlier diagnostic information regarding the patient health. The patient's actual condition is sent through online portal to the medical professionals and the appropriate treatment can be taken to cure the patient [5]. The smart patient health tracking system involves the installation of the heart rate, temperature and humidity sensors to be placed in the room to track the condition of the patients. After processing, all the values are sent to the doctor to check the state accordingly [6]. The signals of sensors such as temperature, EEG and heart beat readings are passed through amplification and signal conditioning system to raise the gain of the signals. Using any microcontroller like Arduino or Raspberry pi or beagle bone black, data can be sent to cloud platform for storage and analysis [7]. The IoT-based system is capable of providing real-time information about the patient parameters, as the internet is a prime communication channel, the security of the cloud and data is one of the challenging issues [8]. With the advancement of internet technologies like cloud computing, edge computing, fog computing, the wearable healthcare monitoring system could be seen in everyday usage in the coming years [9, 10]. The measurement of biomedical signals with the various sensors is a prerequisite in the development of a health monitoring system, that may be utilized for physical rehabilitation and real time tracking of disabled individuals [11]. Portable biosensors integrated with wearable smart devices can provide the record of the individual daily activities and assist in managing the health and thus prevent the complications in the life-related diseases of the individual [12]. The other key challenge in the development of a smart health monitoring system is the personal health dashboard (PHD), through which the biomedical data collected by sensors is easily accessible to the physician and team of specialists for evaluation and analysis purposes. A similar PHD was developed by Brahmni et al. in which a cloud based system is deployed to manage the big data of patients to monitor and detection of presymptomatic COVID-19 [13]. The key challenge is to deploy the IoT system with encryption and high level of security to safeguard the data from breach. The other key challenges to store the large chunk of patient data on the cloud from where the data could be retrieved without latency issues. The novelty of this system is that it could be deployed on the individual patient's bed and a real-time data of patients could be shared with physicians with the help of an internet-supported smart device. This health monitoring system could also be transformed into a wearable device to monitor vital health parameters, thus helping take preventive measures against COVID-19 and other diseases.

The research article is arranged as follow. "Introduction" discusses the related work on smart health monitoring systems. Methodology along with work flow for implementation of prototype is presented in the "Methodology". "Details of System Components" focuses on the different hardware components with design strategy is discussed in "Design of System". "Result and Analysis" discuss the performance evaluation of the system with the procurement of patient's data. The last section presents the conclusion and futuristic studies that can be implemented to make the IoT based smart health system a secure and efficient one.

Related Work

Many researchers have carried out the work for the prediction of health using smart healthcare IoT. Hamizah Anuar et.al. discussed the development of wearable CBT (Core Body Temperature) sensor device based on a single heat-flux concept. Experiments have been done with the sensor on the various parts of the body and the most reliable CBT estimation is experienced on the forehead because there is lowest mean difference of about 0.05 °C between CBT sensor and clinical thermometer [14]. Po-Wei Huang et.al. demonstrated the use of the algorithm based on Neural Network Regression to increase the length of the distance range between 50 and 100 cm. The automatic face tracking feature requires the human face should be focused appropriately while measuring. The information and results can also be viewed through App and Web [15]. Rahaman et al. discussed the different types of smart health monitoring systems and focused on the advantages and shortcomings of the technologies deployed in health care systems [16]. Huang and co-workers have developed a wearable temperature measurement system that can be utilized in healthcare applications [17]. A comprehensive review was done by Albahri et al. on different IoT based technology that could be utilized for telemedicine and healthcare services for prevention against various diseases [18]. A study was carried out to monitor students health through IoT based wireless system having a capability of a real-time alert that can be sent to parents/guardians [19]. On a similar research path, a remote COVID-19 patient monitoring system was developed by some researchers incorporating the measurement of vital body parameters such as PPG, ECG, temperature for identifying the patient health status. In addition, they also discuss the issues related to security concerns in IoT based smart health systems [20]. Bassam et al. demonstrated the application of wearable health monitoring system for COVID-19 patients having a real time tracking feature for location tracking with the embedded GPS. The whole system is connected to android interface through API to track the recovery and health condition of recovered patient [21]. A similar framework proposed by Paganelli et al. discussed various architecture utilization for monitoring of COVID-19 patients that could assist in detecting the COVID-19 [22]. The proposed architecture includes three layers mainly i.e. data acquisition layer, data distribution layer, and application layer. But most IoT-based health systems suffer from a few problems such as delay in communication, latency, etc. A solution to all these problems can be resolved by employing the fog computing along with data mining algorithms [23]. The security of patients data is one of the prime concerns of the IOT-based smart health system, so block encryption based model could be utilized to secure data on the cloud [24]. Apart from common disease detection from measuring vital parameters of body, the other parameters such as gesture, facial expression, body language could be sensed to determine the seizure or non-seizure, epilepsy conditions which could assist doctor to take decision on the treatment of the patient through remote monitoring [25]. Bhatia et al. demonstrates the use of IoT based home system for predicting the urinary infectious diseases like diabetes, cystines, hepatitis, liver disease etc.[26]. Another study discuss the futuristic role of IoT in health monitoring of person focusing on disease management, patient experience, effective treatment and role of 5G in communication [27]. A work by research group of Kondaka discuss about the role of machine learning in assessing and managing the data on cloud for prediction of disease accurately. The deep learning strategies can be utilized to reduce the flaws and errors in IoT smart health system [28]. A detailed survey was carried out by Li and co-workers on effectiveness of machine learning with big data analytics to cater the problems like cloud security, storage allocation, communicating delay, data retrieve, etc. [29]. The IoT system could be utilized for prediction of sedimentary behaviour of individual using machine learning techniques by assessing the behaviour, gestures, health parameters etc. [30]. An IoT/WSN based cloud system was proposed by Onasanya et al. for detection and treatment of cancer patients focusing on the major challenges such as security and efficiency [31]. Another IoT system was developed for the identification of potential COVID-19 patients with the help of eight different learning algorithms which helps to segregate the cold symptom from the COVID-19 symptoms [32]. A study discusses the use of IoT system for monitoring of patients in smart city so that ambulance and other assistance could reach patients place[33]. Wan et al. developed the wearable IoT health monitoring system having its own network known as body area network in which different sensors are continuously measuring and storing the parameters [34]. All the IoT technology were either deployed to hospital, or to home or wearable, so in each of application area the system suffers from some of the concerns. Uslu et al. discuss about some of the factors such as infrastructure of IoT layer, intelligent computing, big data analytics, network traffic that must be considered while designing and implementing the automated IoT health monitoring system [35]. There are certain major issues that are encountered when IOT based health monitoring system is designed which includes mainly misuse of patient information, cybercrime cases, data aggregation etc. [36]. Tracking of COVID-19 cases is of prime importance which assist the Govt. authorities to track the patients and thus preventing the further spread which would be possible with the assistance of IOT based tracking system [37]. Real time monitoring of COVID-19 patients with the help of big data on biomedical signals could brought down the transmission cases of COVID-19 [38].

Methodology

IoT-based health monitoring system differs from the normal healthcare system in a very efficient way. Therefore, it becomes a bit challenging to achieve the required results and performances through IoT. Working with IoT is related to the embedded world as the sensors use electronic data signals. Initially, devices such as sensors, detectors, monitors and microcontroller are connected altogether for synchronization. The sensors and detectors detect the signals in analog form, which needs to be further converted into digital form. The inbuilt analog to digital conversion is performed through the microcontroller to get data in proper digital format. The data are sent to Raspberry Pi that is being used as a microcontroller. Nowadays, the Raspberry Pi is most commonly and widely used in Internet of Things. After the conversion of data, storage of data is performed. The data are being sent to the cloud or server. In this research, a local server is used, which shows the variations of the values or the readings measured simultaneously.

The working of the proposed work is shown as block diagram in Fig. 1.

Figure 2 shows the flowchart of the steps performed in the whole process. It shows the order of the workflow and steps in the sequential order, including the initialization, setting up of protocols successfully, reading sensor values accurately, sending measure values to display monitor and cloud server to store sensor data.

Details of System Components

The system consists of hardware components that are a prerequisite for the development of the prototype. These include the microcontroller with inbuilt ADC, blood pressure sensor, contactless temperature sensor, and oximeter. The COVID-19 virus first enters through the nostrils and mouth and move towards the respiration system of human. The blood pressure was found to be high in the case of COVID-19 patients, so measurement of blood pressure is one of the vital parameters in detecting COVID. The temperature and oxygen level of COVID patients must be monitored, which helps to track and detect the probable COVID-19 patients. The oxygen level in COVID infected persons were found to be drastically reduced, so oximeter is used to measure the oxygen level in the individuals. All the sensors are to be interfaced with the microcontroller (Raspberry Pi), to record the data and communicate to the cloud for storage and further processing.

Raspberry Pi

The Raspberry Pi is a single-board computer about the size of a credit card (Fig. 3). The Pi runs a version of Linux/android that was customized to work on the ARM processor that drives it. With Linux on board, the functionality of this small device is enhanced that it can be utilized for automating systems. It can work with sensors and external devices and has inbuilt display and lan port for communication purposes. The added advantage is that it can be programmed with python.

Blood Pressure Sensor

The BP sensor is wrapped around the arm and it gives three different values or data to the microcontroller. In these values, first one is systolic, second is diastolic and third value is pulse rate and are fed to the Raspberry Pi. Sensor BP0001 is board mount blood-pressure sensor which is used for this research work, having pressure range of 0–300 mg and an accuracy of about $\pm 1\%$. The schematic of BP sensor is shown in Fig. 4.

Temperature Sensor

The MLX90614 non-contact temperature sensor is placed near the human body and it detects the temperature values without physical contact with patients. The MLX90614 is

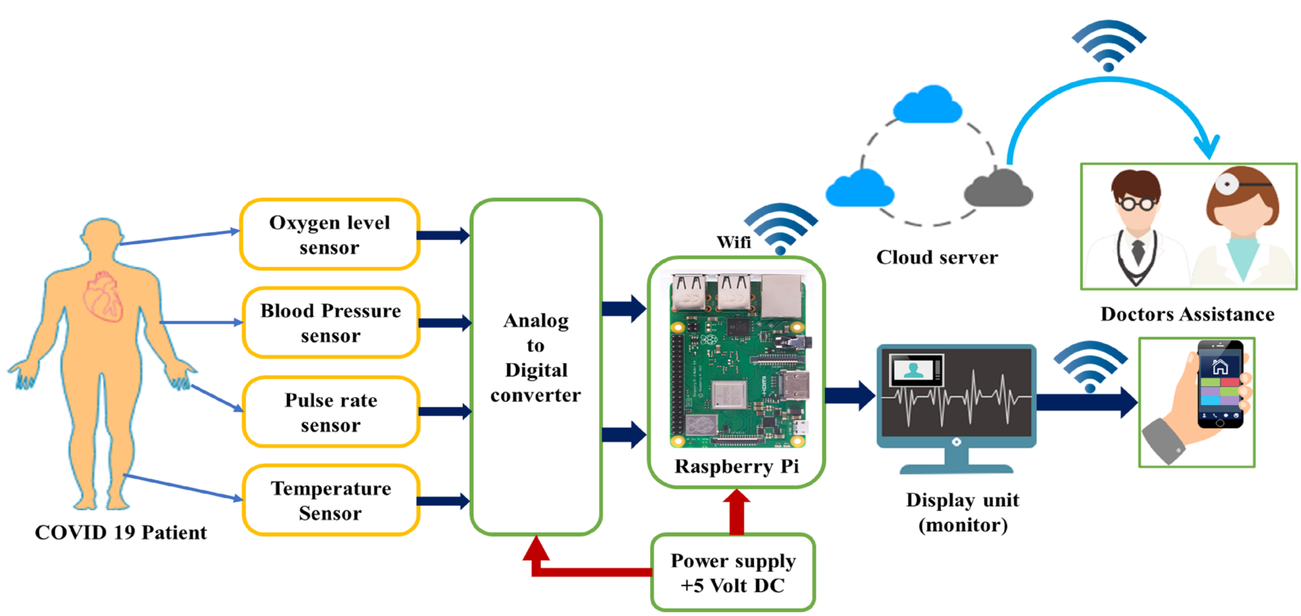

Fig. 1 Block diagram of proposed IOT smart health system

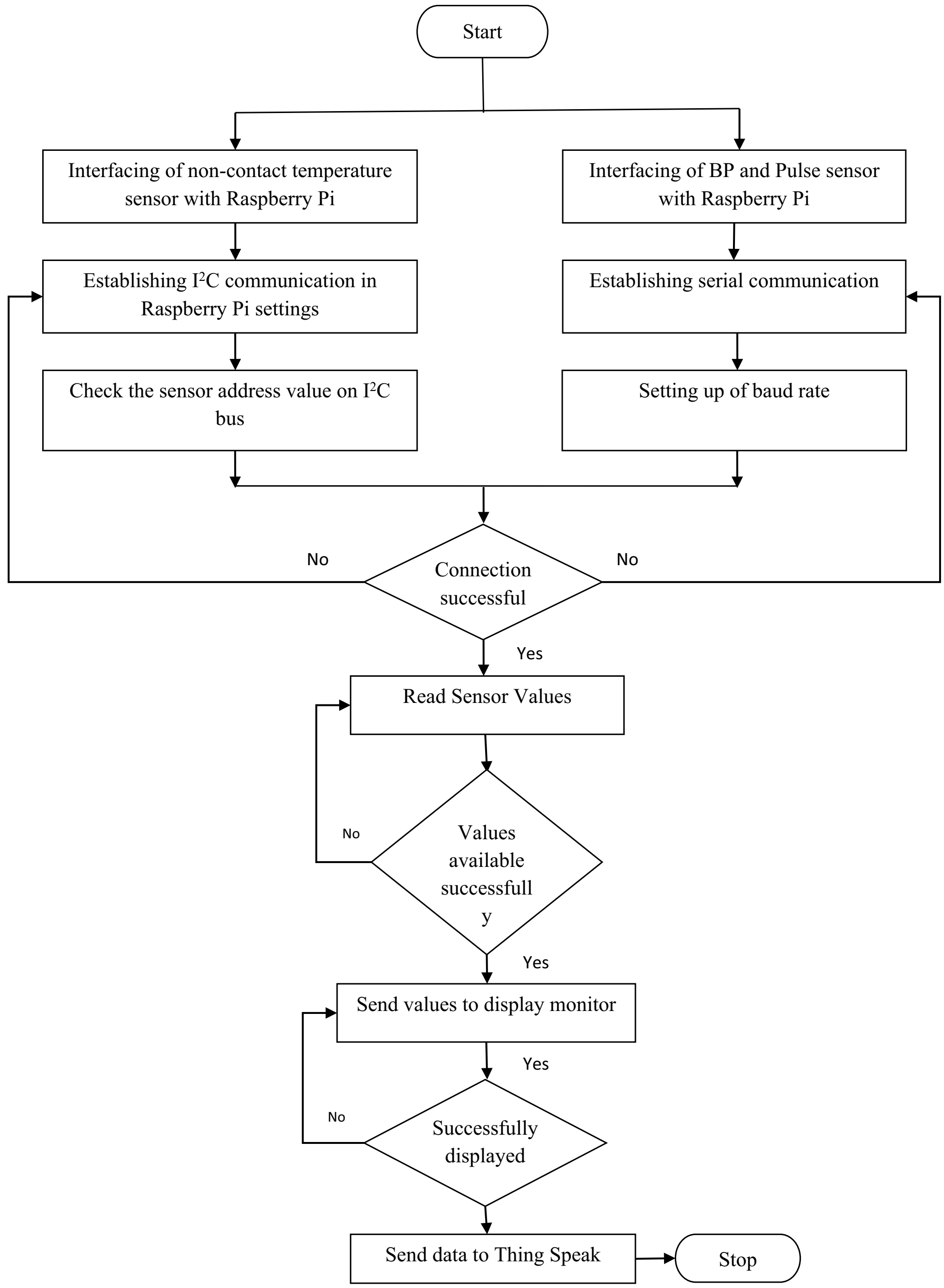

Fig. 2 Flow chart of IOT smart health system

integrated with a low noise amplifier, 17-bit ADC and powerful DSP unit thus achieving high accuracy and resolution of the thermometer. The schematic of sensor MLX90614 is shown in Fig. 5.

Pulse Oximeter

The MAX30100 is an integrated pulse oximetry and heart-rate monitor sensor module. It combines two LEDs, a photodetector, optimized optics, and low-noise analog signal processing to detect pulse rate and heart-rate signals. Pin diagram and schematic of the sensor MAX30100 are shown in Fig. 6.

Data Storage and Display

A 2 Inch LCD Display Module is utilized in developed prototype smart health monitoring system. The LCD

Fig. 3 Raspberry Pi

Fig. 4 Blood-pressure sensor BP0001

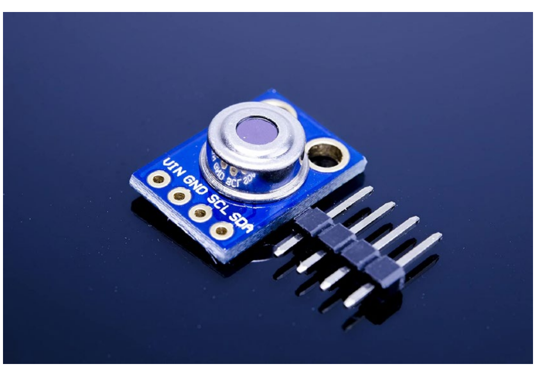

Fig. 5 MLX90614 temperature sensor

display Module is in-plane switching screen (IPS), having a 240 × 320 resolution. It has an inbuilt embedded controller and, communication is carried out by SPI interface. The SPI interface requires minimum GPIO pins for controlling its functionality. Figure 7 shows the schematic of LCD display.

Design of System

The whole workflow consists of the three main steps: data capturing, data processing followed by data storage, and displaying patients' parameters on the monitor. Data capturing is the most important step as the precision and accuracy of measurement system depend solely on this step. In data capturing, the sensors to be used are connected with microcontroller i.e. Raspberry Pi. The sensor outputs are connected with the GPIO pins of Raspberry Pi, which have been selected. The output pin of BP sensor i.e. Tx pin is connected with the Rx pin of the Raspberry Pi. After making the hardware connections, the power supply of + 5 V is given to the microcontroller and to the sensors. The SMPS based power supply is used for powering the raspberry pi module as well as the various sensors. The maximum power consumption of whole system is 7–8 W as raspberry pi could be configured in power saving mode when no data transmission is taking place with Wi-Fi. All the sensors used for measurement and data acquisition are IC based which takes small value of load current. The efficiency of power SMPS used to power up all the devices is relatively high (80–85%), some of the efficiency is lost in heat dissipation. The developed system could be scalable to optimally monitor five patients simultaneously with different biomedical sensors for each patient.

Data Capturing

Initially the sensors which are to be used are connected with microcontroller i.e. Raspberry Pi. The sensor outputs are connected with the GPIO pins of Raspberry Pi which have been selected and configured as input. The output pin of BP sensor i.e. Tx pin is connected with the Rx pin of the Raspberry Pi. After making accurate hardware connections, the power supply of + 5 V is given to the microcontroller and to the sensors. The MLX90614 non-contact temperature sensor is placed near the human body and it detects the temperature of patient. The BP sensor is wrapped around the arm and it gives three different values or data to the microcontroller. In these values, first one is systolic, second is diastolic and third is pulse rate which are to be fed to the Raspberry Pi for processing.

Data Processing

The MLX90614 works on I2C/IIC communication protocol. This sensor measures the ambient temperature as well as the

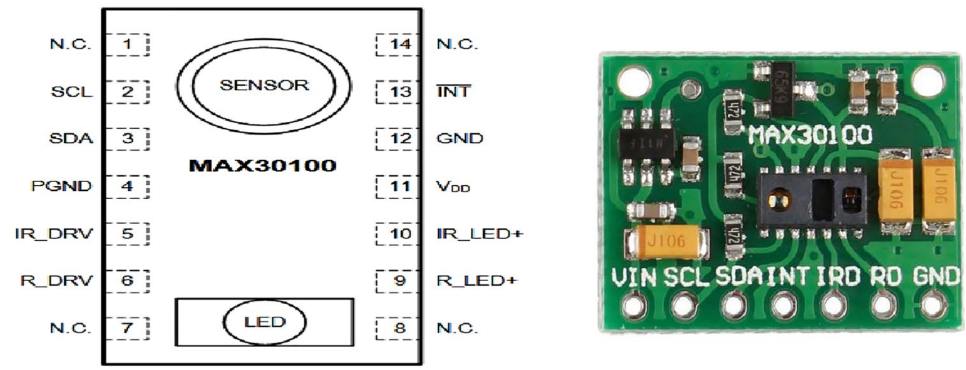

Fig. 6 Pin diagram of MAX30100 Pulse Oximeter Heart Rate Sensor Module

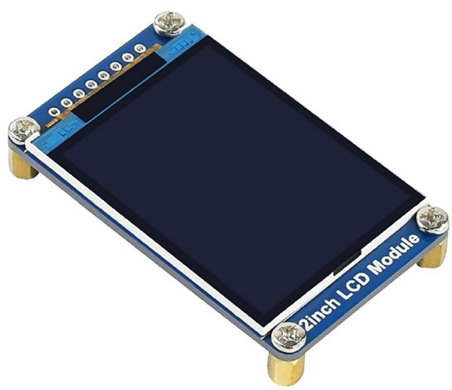

Fig. 7 Schematic of LCD display

object temperature. The steps of interfacing MLX90614 are shown below:

1. Enabling I2C from Raspberry Pi interfacing settings.
2. Downloading the packages or libraries of MLX90614.
3. Installing of the packages.
4. After installing, connections are to be made of MLX90614 with Raspberry Pi circuit.
5. After connections are done properly, verifying the sensor address value on I2C bus using the command i2cdetect-y1.
6. If address value is found out successfully, it will be shown on the terminal.
7. Check the variations in values if they vary by moving hand over it.

Data Logging

This is the last step in the design of the system. In this step, the communication channel on ThingSpeak is created for data logging.

1. Signup for ThingSpeak.
2. Creation of own channel.
3. Getting API Key in ThingSpeak.
4. Making file of python code with.py extension.
5. Run the python code.
6. See the values of sensors on the screen output.
7. Check ThingSpeak site for Data Logging.
8. Chart on the ThingSpeak channel which shows the various graphs according to the varying values.

Table 1 Comparison of data values measured by Heart rate sensor and commercial sensor

Number of samples	Actual bpm	Observed bpm	Relative error ($\%\epsilon_r$)
D1	68	69	1.47
D2	69	71	2.89
D3	70	70	0.00
D4	72	70	2.77
D5	71	73	2.81

The outputs of the sensor values captured by Raspberry Pi are now sent to the display monitor to view the corresponding values. By creating channel on ThingSpeak, the required information is displayed on the screen and at the same time is stored on the cloud for maintaining further records. In this way, the required information is displayed on screen and at the same time is stored on the cloud which can be retrieved by the doctors for future analysis. The data from the cloud can be easily assessed by other users and researchers.

Result and Analysis

The designed prototype is tested on different patients or subjects to obtain the performance of health monitoring system. For performance analysis, four patient parameters i.e. heart rate, body temperature, blood pressure and SPO2 were measured. The efficacy of the system can be evaluated by comparing the measurement data with commercial sensors available.

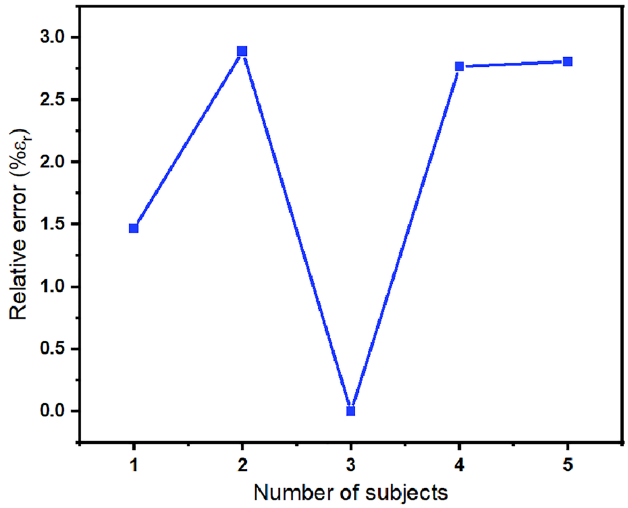

Fig. 8 Relative error vs. number of subjects in Heart rate sensor

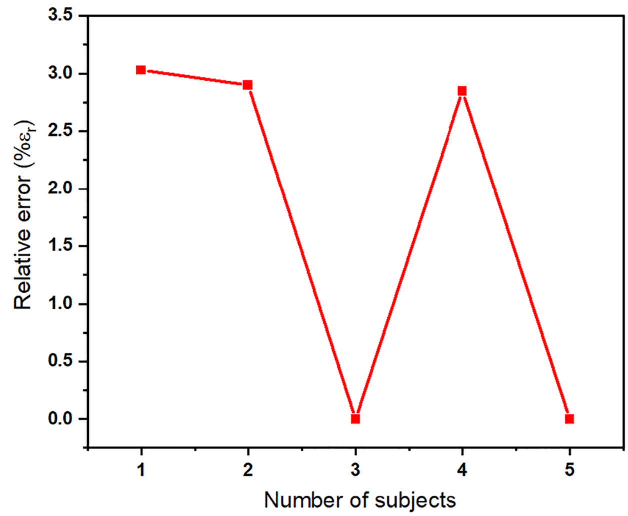

Fig. 9 Relative error vs. Number of subjects in BP measurement

Table 2 Body temperature collected with MLX90614 temperature sensor and its comparison with commercial non-contact thermometer

Number of samples	Room temperature measured	Actual body temperature	Body temperature observed	Relative error ($\%\epsilon_r$)
M1	29° C	33 °C	34 °C	3.03
M2	28 °C	34 °C	35 °C	2.90
M3	29 °C	34 °C	34 °C	0.00
M4	30 °C	35 °C	36 °C	2.85
M5	29 °C	35 °C	35 °C	0.00

Table 3 Blood Pressure data collected with the developed IOT system

Number of samples	Systolic	Diastolic
D1	110	61
D2	101	64
D3	115	66
D4	100	59
D5	120	80
D6	141	90

Table 4 Comparison of developed SPO2 system with commercial oximeter

Number of samples	Actual SPO2 (in %)	Observed SPO2 (in %)	Relative error ($\%\epsilon_r$)
D1	98	98	0.00
D2	96	97	1.04
D3	97	97	0.00
D4	98	99	1.02
D5	95	96	1.05

Table 1 illustrates the comparison of measured data of heart rate with the commercial sensor. The relative error was found to be in the range of 0.00–2.89. Figure 8 shows the plot between the relative error and the number of subjects. The patient's body temperature was measured with MLX90614 sensor and was compared with a commercial non-contact sensor (Table 2). The maximum relative error was computed as 3.03, whose value depends upon environmental conditions such as humidity as well as the accurate placement of the sensor. Figure 9 displays the plot between relative error and the number of subjects regarding the temperature measurement. The blood pressure is measured with the developed handcuff system, and observation has given in Table 3. The developed system has utilized a separate SPO2 sensor to measure the oxygen level in COVID-19 patients (Table 4). The maximum relative error was found to be 1.05 which indicate the high accuracy of O_2 measurement system. Figure 10 displays plot between relative error and number of subjects.

The image of the developed IOT health system showing the connection of various sensors with microcontroller and BP monitoring is shown in Fig. 11. The snapshots of the ThingSpeak online server storing the patient's data are shown in Fig. 12a–d. The prototype of a smart health monitoring system can be placed and installed on the bed of the COVID-19 patient. The real-time measured data are collected, stored and deployed to cloud. From the cloud application ThingSpeak, the doctors/physicians can access the data related to a particular patient. An online access point link is to be shared with the nurse and doctors for monitoring purposes. This link could be opened from any smartphone, smart-tablet or internet-connected computer. Each patient is

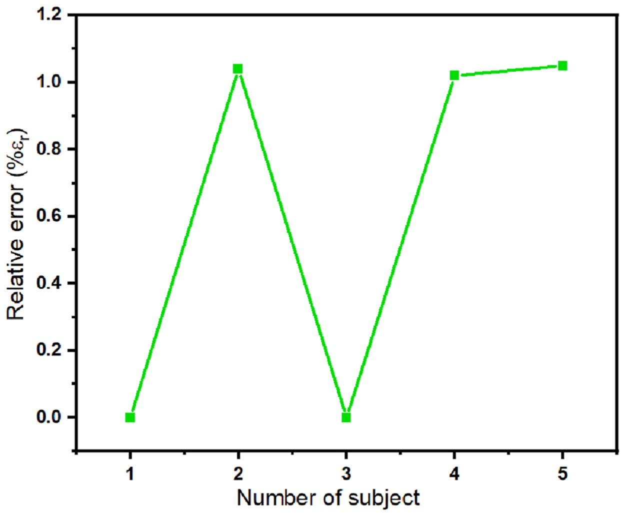

Fig. 10 Relative error vs number of subjects in SPO2 measurement

identified with unique identification number generated when a patient is admitted for observation and treatment. Even the COVID-19 patient can be removed from the COVID ward when all the patient parameters are under the limit. This type of system would assist the doctor in deciding the treatment of COVID-19 patient. The limitation of this system is that the same set of sensors are to be used for measurement purposes. The other major limitation of this system is the security as data spoofing could be done. So, a separate cloud with encryption-based technology could be required to make the whole system highly secure. The data would be encrypted before it is shared with any of the physician/doctor. A future upgrade would be the prescription of the patient could be linked to its country identification id or health card digital id. For individual patient monitoring, separate pair of biomedical sensors are to be deployed to individual COVID-19 patient's bed. The added advantage of this system is that this system can be even deployed to non-COVID-19 patient treatment, and the cost of this system is relatively low. This smart system can reduce the burden on the hospitals and physicians, which ultimately helps in the early detection and treatment of COVID-19 disease. This developed system would be beneficial to a large society as the people from low-income sections are mainly dependent upon the Government hospitals and large number of these systems due to its low cost, could be deployed with much ease and could assist the patients.

Conclusion

The proposed smart health monitoring system provides ease to the doctors to identify the patients' information individually simply on the display monitor at their place. Doctors can distinguish the data of the particular patient regarding previous values with the present one. Along with data logging on the cloud, the Internet of things also provides opportunities to add more advanced features or benefits and more biomedical sensors to this system. Therefore, the technology of IoT makes this monitoring system more flexible and more updatable in future. In this proposed work, we have taken advantage of technology to make patients' lives easier for diagnosis and treatment by monitoring a person's blood pressure, heart rate, oxygen level, and temperature. Thus contactless tracing and treatment of COVID-19 patient is quite possible with the usage of a developed IOT smart health monitoring system. The

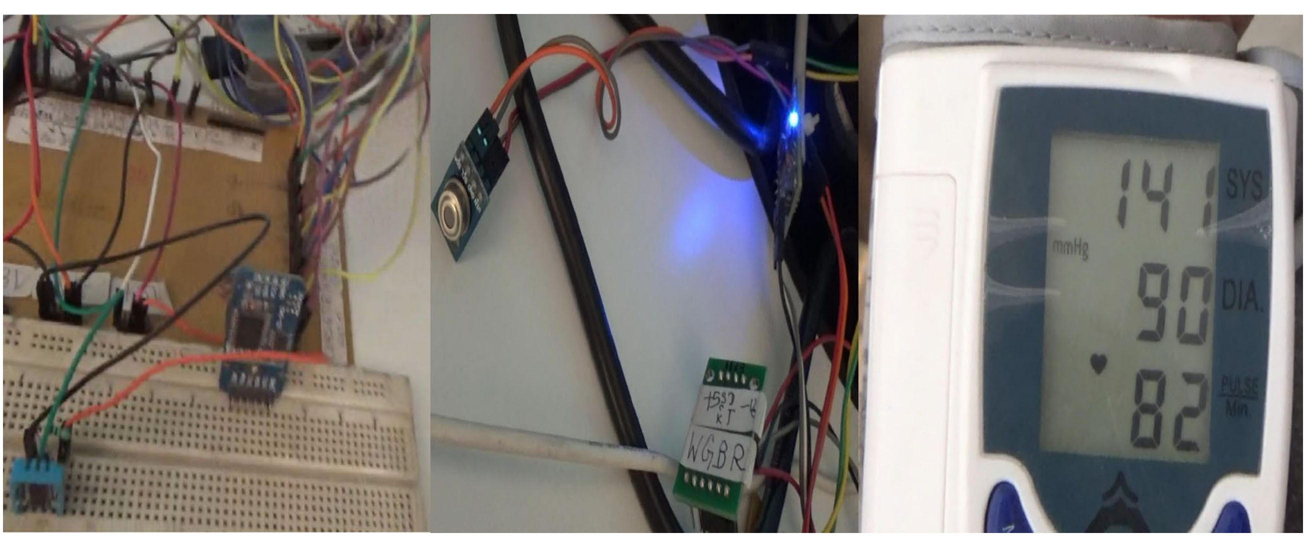

Fig. 11 Screenshot of developed prototype of smart IOT health monitoring system

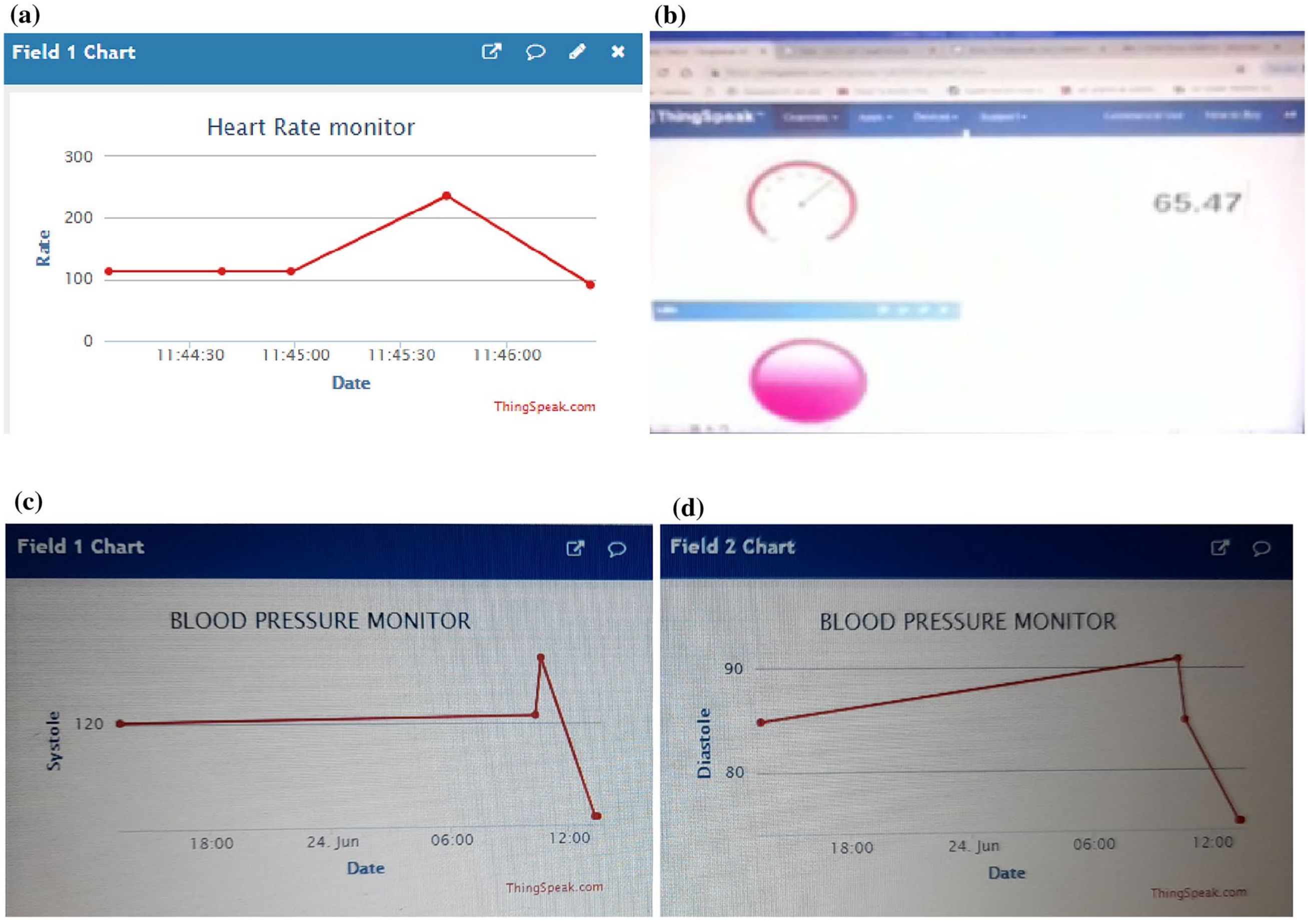

Fig. 12 **a** Heart rate measurement **b** Temperature measurement **c** Systolic **d** Dystolic blood pressure monitor on ThinkSpeak

key challenges in this developed prototype are securing the patients' data and the availability of the data to physician in stipulated time with less delay. One of the ways is to encrypt data which would secure the data from a security breach. This would be done with the help of using the edge computing technique through which on-demand COVID-19 patient data would be available for analysis purposes. The deployment of machine learning algorithms such as LSTM would help identify the probable COVID-19 patients from large populated data, reducing the burden on hospitals and health services.

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Declarations

Conflict of interest All the authors declare that he/she has no conflict of interest.

Ethical approval This article does not contain any studies with animals performed by any of the authors.

Informed consent Informed consent has been obtained from all individual participants included in the study.

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