Smart Non-invasive Physiological Parameter Monitoring System Using IoT and Blynk App

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***Abstract*—This work aims to provide an advanced, portable and non-invasive multiple physiological parameters monitoring system using the Internet of Things (IoT) platform and Blynk App. The device detects essential physiological parameters non-invasively including heart rate (bpm), blood oxygen saturation (SpO_2), blood glucose (mg/dL) and body temperature (°C or °F) from a person's finger, peripheral part of the body or forehead. The sensors like pulse oximeter MAX30100 to read both heart rate and blood oxygen saturation, MLX9606 for sensing the body temperature and IR sensors to interpret blood glucose by near infrared optical method, have been calibrated and integrated with Arduino microprocessor and node MCU. The signal from the device is then sent to the Blynk App installed in an Android phone via a Wi-Fi connection, allowing the user to record and monitor the data. Test results showed that the device is capable of sensing and monitoring the physiological parameters and can transmit real time data instantly after sensing to the user. This non-invasive method of sensing parameters showed an average accuracy of 99.2% in temperature measurement, 99.07% in blood oxygen saturation level measurement and 90.52% in blood glucose measurement.**

***Keywords*—blood glucose, body-temperature, blood oxygen saturation, Blynk App, IoT, non-invasive, near-infrared, pulse oximeter**

I. INTRODUCTION

According to World Health Organization (WHO), millions are suffering from diabetes and cardiovascular diseases. These are the leading cause of death in many nations, accounting for more than 14 million deaths globally. The interval between the development of the main side effect of any cardiac disease or diabetes and the request for medical help varies dramatically across people and can be fatal. One of the most important conclusions drawn from epidemiological data is that allocating resources to early identification and treatment of heart disease and diabetes has a higher chance of lowering the fatality rate than enhanced post-hospitalization care. As a result, novel approaches are required to reduce the time spent on treatment.

For avoiding pain during measurement non-invasive way of measuring physiological parameters is preferred. A non-invasive medical device popularly used to detect the oxygen saturation in blood is known to be a pulse oximeter. It is embedded with a LED and a photodiode which acts as a transmitter and receiver respectively. When the finger is placed in the pulse oximeter, a specific wavelength oflight is emitted by the LED which is absorbed by the blood. The light is also reflected, transmitted,absorbed, and spread on the skin and under the skin before it reaches the photodiode. Two different types of pulse oximeter sensor exist such as transmittance sensor and reflectance sensor for measurement which differs from each other based on the placement of the LED and the photodiode. In the transmittance sensor type, the LED and photodiode are on the same line. When a particular wavelength of light is emitted by LED through the fingertip tissues,the light that penetrates the tissue will be accepted by the photodiode placed opposite to the LED. In the reflectance type pulse oximeter, both the LED and photodiode are found next to each other on the skin surface. The specific wavelength of light emitted by LED passing through the tissue is absorbed by blood and reflection, acceptance phenomena happen on the photodiode for the remaining part of the light.

Glucometer plays a significant role in monitoring the glucose level of blood to avoid complications of diabetes and damage to organs. For avoiding pain and also infection caused due to invasive methods, non-invasive methods are prominently preferred. Skin Temperature can be detected by using both contact and contactless sensors. A Non-Contact Thermometer allows us to check the body temperature of a person from a minimal distance of measurement. Sensing the temperature without even touching the body is very important considering the current pandemic situation.

This paper is aimed at providing a non-invasive method of detecting physiological body parameters. The rest of the research article is organized as follows. Section II analyses the existing methods available for monitoring body parameters. Section III describes the materials and methods proposed in this research work along with the hardware implementation. Section IV provides a discussion and analyses of results. Finally, Section V summarizes the proposed technique and also suggest a scope for future improvements.

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II. Literature Review

This section comprises existing methods and technologies used for measuring the physiological parameters. Authors developed a pulse oximeter using infrared LED and this system detected the light after being passed through a patient's finger from an emitter [1]. The detected analog output of the sensor circuit was fed into a Node microcontroller that computes the heart rate and oxygen level from these numbers. The designed system was made accessible and portable. By connecting with the Internet, the values were uploaded to a cloud computing web host called Thing Speak, Remote doctors can assess the condition of the person by checking the result from the web. The continuously monitored data was also made available to the client on their mobile phone. They reported an accuracy of 96.9% as the least value for measuring the heart rate using their prototype as compared to the standard device measurement. The most important factor to consider while developing the monitoring system is its ability to alert the health care providers when the patient is in critical condition. For achieving an instant alert and remote control, the quality of the internet connection determines the communication speed [2, 3]. Many researchers have developed cost-effective devices to measure pulse rate (bpm) and blood oxygen saturation (SpO_2) using IoT technology [4–6]. The performance of those developed devices is compared with a standard medical device. For instance, in 2021 a sensor kit comprising of Atmel ATMega 328P MCU and MAX30100 to monitor the heart rate and blood oxygen saturation was developed. They used the device for measurement on 12 persons and the results were compared with a commercially available, Rossmax SB150 pulse oximeter. They observed a deviation of 0.8175% for pulse rate and 0.425% for blood oxygen which validated the accuracy of their algorithm and implementation [7]. By the end of 2018, researchers developed an IoT based Pulse oximetry to monitor the conditions of heart functioning along with GSM to communicate the real-time monitoring data to the health advisors [8]. In this research work, a Reflectance pulse oximetry sensor was used to make it wearable on wrist.

To measure the blood glucose level, glucometers are prominently used. The amount of glucose varies during fasting, after having lunch and it may increase after a meal. Few non-invasive devices were reported for glucose measurement in the past, but the performance of those devices was not that accurate [9–12]. A non-invasive clipping type optical sensor was designed and used for SpO_2 measurement by the authors in 2021. They achieved an average relative error of 1.59% in SpO_2 measurement using their device [13]. So, a compact wearable type of noninvasive device is required to monitor the blood glucose level at home. In our work, a non-invasive wearable type of glucometer is developed for monitoring glucose.

The non-contact thermometer is being used for monitoring body temperature even in healthy conditions to detect the disease early. Based on the research paper written by the end of 2020, the authors developed a wireless remote body temperature monitoring system using Arduino integrated with different sensors and an open-source internet connection. They used an internet network via Wi-Fi connection to be linked with an online portal on a computer or smartphone. They used two types of sensors such as LM35 and MLX90614 for temperature measurement and compared the results obtained. A temperature deviation of 15°C was observed between the readings taken using LM35 and MLX90614. Since this prototype faced a limitation in design, this was not recommended for large-scale applications [14, 15]. It can be scaled into smart measurement using smartwatches and thermos-regulator tools.

A non-contact thermometer device operating on its own at a close range without involving humans for detection is required to be designed and mounted at gate terminals of important places like airports, shopping malls, railway stations and so on in 2021. One such device was developed and tested for its performance by the authors [16]. To display the detected body temperature, an LED running text display was equipped with the hardware device. In case of a person's measured body temperature exceeds the threshold value of 37.5°C, an alarm system integrated with the device alerts the officer to seek medical help. The design used a cloud-based technology provider (IoT) integrated with the nearest hospital to provide first aid immediately for someone who is exposed to Covid -19 virus. A precision of 99.8% and an accuracy of 99.6% were achieved using this IoT-based contactless temperature monitoring system. The limitation of the device is that it is not handy/portable and works only in internet coverage areas. Similarly, few other non-contact thermometers for human body temperature measurements were developed for using during the pandemic situation [17–20].

Another non-contact tool used for screening the body temperatures of people at the entrances of large public gathering spots in general to restrict public access was developed by the authors. The hardware design was constructed using TECNIMED Visio Focus PRO 0648, FLUS IR-805B, Axillary mercury-based analogical thermometer, Berrcom JXB-178. They demonstrated the strong impact of distance of measurement, light conditions and angle of inclination while measuring body temperature using a non-contact infrared point thermometer which could invalidate the screening result. Accurate lighting conditions, and monitoring proper angle of inclination and working distance are mandatory to avoid large discrepancies between the subsequent measurements [21]. Recently in 2022, an IoT and fog computing based human body temperature measurement along with facial images was developed and implemented in real-time at multiple nodes [22]. The monitored data at multiple nodes were communicated to the cloud through internet services.

There are many researches done on measuring the physiological parameters individually and very few devices are designed to monitor multiple physiological parameters. A portable device was developed to predict multiple physiological parameters such as blood glucose, body temperature, blood oxygen concentration and pulse rate, but the designed device cannot remotely control the parameters [23]. Based on the broad literature survey, it is observed that most of the previous works are involved in developing a separate device for monitoring every physiological parameter. So, a single smart device integrated with the options for multiple physiological parameter monitoring is required to be developed. Such a device should be capable of monitoring the parameters remotely and the monitored real-time data should reach the doctors instantly. So, we have chosen the objective of designing and developing a smart multi-physiological parameter monitoring system using IoT technology which is presented in this paper.

III. Materials and Methods

The proposed system to monitor the physiological parameters using a non-invasive technique is represented in the form of a block diagram as shown in Fig. 1. The monitoring system consists of three main parts such as pulse oximeter system, glucose monitoring system and body temperature monitoring system. Using this non-invasive methodology, the glucose level, oxygen concentration, body temperature and heart rate are measured. The pulse oximeter sensor is connected to the node MCU ESP8266 and the output from the microcontroller is displayed in the OLED and also in the Blynk App. The MLX90614 temperature sensor, APDS - 9960 Proximity sensor and IR sensor are interfaced with the Arduino nano. The communication between the system (laptop) and Arduino Nano is established by the serial monitor. The processed output of the sensors is used to drive the piezo buzzer, plotted in the Excel App and displayed in the OLED.

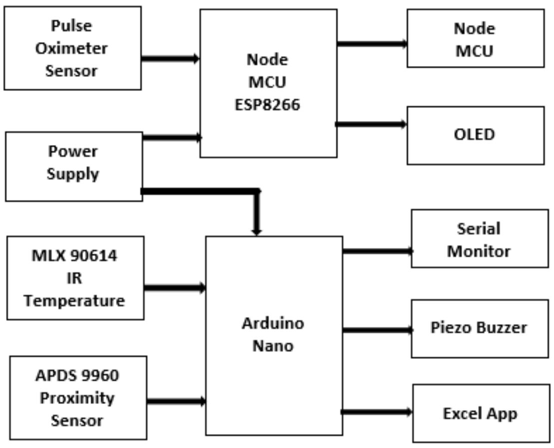

Figure 1. Block diagram of the proposed physiological parameter monitoring system.

A. The Pulse Oximeter System

The pulse oximeter sensor is a cost-effective non-invasive device employed to measure the percentage of oxygen saturation in blood and the heart rate continuously. It works on the principle of difference in absorption characteristics of oxygenated and deoxygenated blood. An integrated sensor with a pulse oximeter and heart rate (MAX30100) is used in this work and is shown in Fig. 2. It is a reflectance-type optical sensor having red, infrared LED and photodetector placed next to each other. Two different wavelengths of light are emitted by the light sources and the absorbance of light by the pulsing blood through the photodetector are measured while keeping the fingertip over the sensor. To cancel the interference of ambient light during measurement, this biomedical sensor has an inbuilt ambient light cancellation feature. It also has a 16-bit sigma-delta analog-to-digital converter with a discrete time filter to provide the output in digital format which is stored in a 16-deep FIFO of the device. This pulse oximeter sensor is interfaced with the node MCU ESP8266 Wi-Fi module that receives the digital data from the sensor through I2C digital interface. The received digital data are processed and communicated to an IoT platform called the Blynk App. The sensor is capable of working in low power mode and is hence suitable for wearable devices.

Figure 2. The MAX30100 integrated Pulse oximeter and heart beat sensor.

B. The Glucose Monitoring System

The glucose level of a person is measured non-invasively using the Infrared sensor (IR). It consists of an infrared LED and an infrared photodiode acting as a transmitter and receiver respectively. The IR LED emits radiation which in case hits an object, and reflects some of the radiation back to the IR receiver. Based on the intensity of received radiation in the IR receiver, the sensor produces an output. For glucose measurement, a second-order polynomial regression equation derived from the invasive laboratory measurements [10] is used and is represented in Eq. (1).

$$b = (8 \times 10^{-5})a^2 + 0.187a + 46.13 \tag{1}$$

In the Eq. (1), α is the analog voltage in (mV) and b is the glucose level in (mg/dL).

When the fingertip is placed near the IR sensor, the radiation from IR-LED passes through the fingertip and it interacts with the glucose molecules. Depending on the glucose concentration of the blood, part of the radiation gets absorbed in the blood and the remaining of them are reflected to the receiver. The received radiation by the photodetector produces an output voltage which in turn is fed to the Arduino nano. This microcontroller is programmed to convert the output voltage into blood glucose level using the polynomial regression equation mentioned in Eq. (1). The measured glucose level is displayed in the OLED display and also in the serial monitor.

C. The Temperature Monitoring System

The body temperature of a person is measured using this non–contact temperature monitoring sub-circuit which consists of a proximity sensor (APDS 9960), an IR temperature sensor (MLX 90614) and a display unit, integrated with the Arduino nano. For non –contact temperature measurement, the MLX90614 digital IR sensor is the most suitable sensor that can measure temperature in the range of −20 ºC to 120 ºC and is shown in Fig. 3. The temperature sensor can measure the temperature using IR rays when the finger/ forehead is placed at a distance of 2−5 cm from the sensor and communicates the data to the microcontroller using the I2C protocol.

Figure 3. The MLX 90614 IR digital temperature sensor.

D. The Blynk-IoT Platform

The sensors integrated into the monitoring system detect the body parameters and they should be stored in the cloud using an IoT platform. In this work, Blynk is used as an IoT platform to store the monitored data and the Blynk App is installed on the users' mobile phones to retrieve the information. This app has a graphical user interface named as a monitoring App that continuously displays the data to the user and also generates a report based on the data updated in the cloud.

E. The Proposed Hardware Implementation

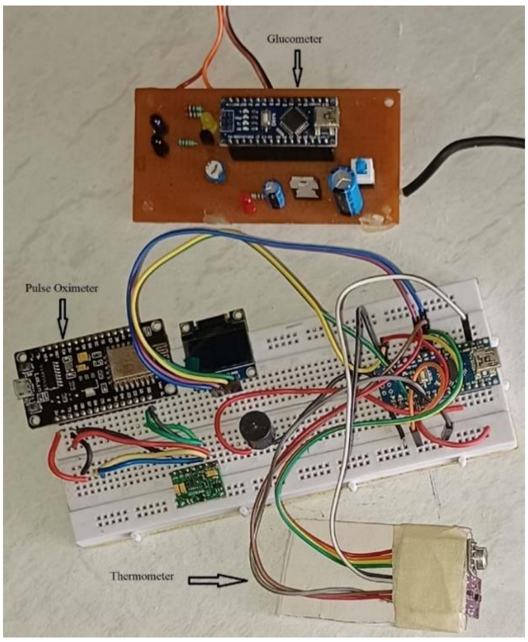

Figure 4. Prototype of the physiological parameter monitoring system.

The actual prototype of the hardware constructed using different sensors, Arduino Nano, node MCU, OLED, and a buzzer is shown in Fig. 4. The DC power supply is provided to all the blocks to initiate their function. The Arduino IDE software is used for programming the microcontroller to receive the data from different sensors and communicate the response to the cloud.

IV. Result and Discussion

The non-invasive multi-physiological parameter monitoring system is designed and developed as a prototype to measure the parameters like heart rate, blood oxygen saturation, temperature, and glucose level. The performance of the prototype is tested in real-time by keeping the finger in front of the sensors and the different parameters measured using the system are discussed in this section.

A. Measurement of Heart Rate and Blood Oxygen Saturation (SpO_2)

The blood oxygen level is a prime indicator to ensure the good health of human beings that indicates the proper distribution of oxygen in the body. At any instant, the amount of hemoglobin bound to molecular oxygen is defined as Oxygen saturation. It measures the percentage of oxyhemoglobin in blood which is a vital parameter to access the oxygen content and oxygen delivery. For normal adults, the value of SpO_2 ranges from (95 -100) %. If the value is less than 95 % while measuring, it is considered as low oxygen saturation which requires an external oxygen supplement. In this project, the SpO_2 and heart rates are measured by keeping a person's finger on the pulse oximetry sensor. The sensed data is processed by the Node MCU ESP8266 and transmitted to the Blynk IoT platform which stores the monitored data. The Blynk App installed in the user's mobile has a graphical user interface (GUI) that continuously displays the monitored data to the user.

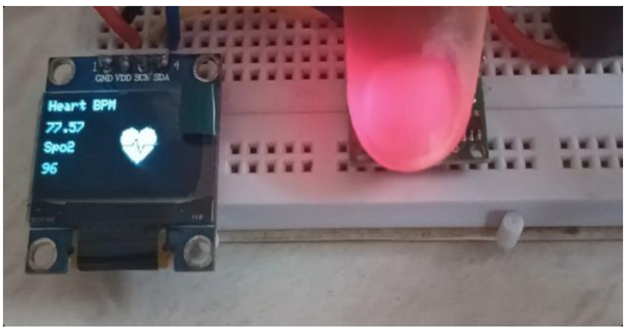

Figure 5. Pulse oximetry sensor output displaying heart rate and SpO_2 in OLED.

The data can also be presented in the form of the report using the App. This would help the health advisor or caretakers to have a continuous track on the health condition of the patient. As soon as the heart rate and SpO_2 are measured for a person, it is immediately displayed on the OLED screen and also plotted in the serial monitor for experimental analysis. If any abnormal value of pulse rate or SpO_2 is observed during measurement, the system instantly gives an alert through a buzzer. It helps the user to take the necessary steps towards further treatment. The sample output of the pulse oximetry sensor measured during experimentation using OLED is shown in Fig. 5. We measured our heart rate in real time using this pulse oximetry sensor which is recorded as 77.57 bpm and the SpO_2 as 96 %. The real time data monitored continuously and processed by the node MCU ESP8266 is presented in the GUI (Graphical User Interface) of the Blynk App in the user's mobile as shown in Fig. 6.

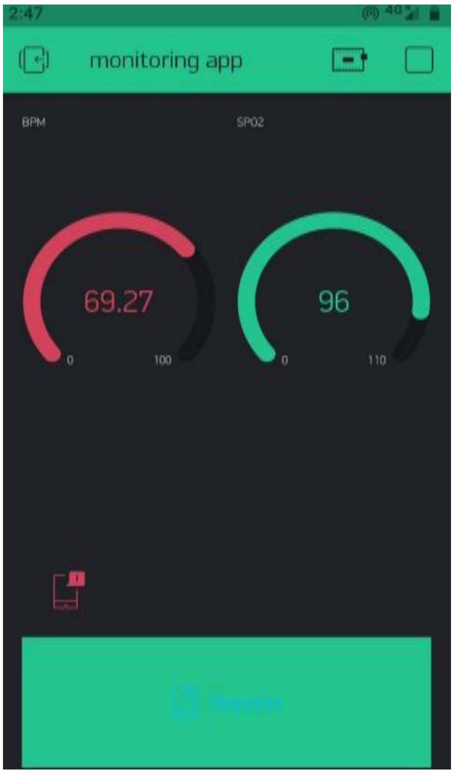

Figure 6. Pulse Oximetry sensor output displayed in GUI of Blynk App in mobile.

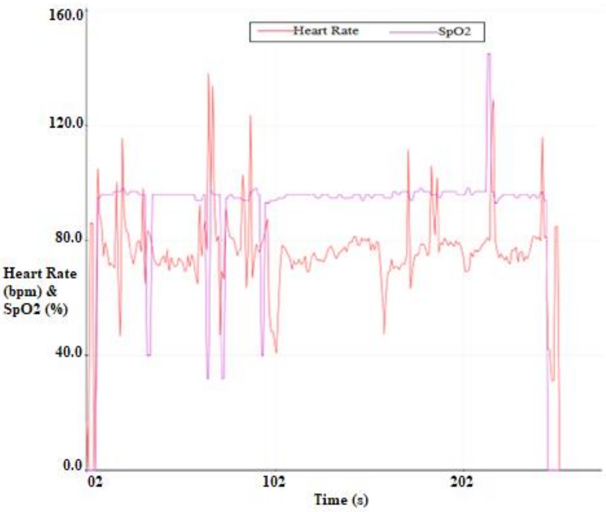

Figure 7. Pulse Oximetry sensor output plotted in the serial plotter.

In addition to the visual display of data in the Blynk App, a report can also be generated. This report can be used by health advisors to take necessary action for patients with abnormal heart functioning. The same pulse oximetry output is plotted using the serial plotter for continuous time and is shown in Fig. 7. The red line indicates the heart rate in bpm and the pink line indicates the blood oxygen saturation in %.

TABLE I. PHYSIOLOGICAL BODY PARAMETERS [24]

Observation	Parameters		
	SpO_2 (%)	**Pulse rate (bpm)**	**Temperature (ºC)**
Normal Reading	96 or more	40-100	36.5 – 37.5
Acceptable to continue Home monitoring	95	101-109	38
Seek advice from general practitioner	93-94	110-130	38.1-39
Need urgent medical advice	92	131 or more	39 or more

The different ranges of heart rate and blood oxygen saturation indicating the status of health conditions in humans as recommended by NHS, London is shown in Table I [24]. This would help detect the health condition of a person preliminarily at home by comparing the value measured against the value in the chart. If any abnormal range of value is detected, then the person should seek the advice of a health advisor for further treatment. This prototype will serve as a preliminary device for monitoring physiological body parameters at home. To assess the performance of the designed prototype for blood oxygen saturation level measurement, a test has been conducted on ten different persons. The SpO_2 of ten different persons measured using both the prototype and the standard pulse oximeter device are tabulated in Table II and the relative error is calculated. The average relative error in the measurement of blood oxygen saturation level is 0.93 %.

TABLE II. BLOOD OXYGEN LEVEL MEASUREMENT OF DIFFERENT PERSONS

Person Number	Measured SpO_2 using our Prototype (L_m in %)	Measured SpO_2 using Standard Pulse oximeter (L_a in %)	Relative error = $\frac{L_a - L_m}{La}$ x 100 (%)
1	97	98	1.02
2	98	97	1.03
3	95	95	0.0
4	95	96	1.04
5	96	97	1.03
6	94	95	1.05
7	96	97	1.03
8	97	98	1.02
9	96	97	1.03
10	94	95	1.05

B. Measurement of Body Temperature

For measuring the body temperature by non-contact method, the APDS 9960 proximity sensor is used which is sensitive for measurement at a distance of 2-5 cm. When the forehead or hand of a person is in close proximity to the MLX90614 IR temperature sensor, it starts sensing the body temperature and displays the output in OLED after being processed by the Arduino Nano as shown in Fig. 8. It shows a detected temperature of 94.12 ºF at the time of measurement. If the sensing part is not placed within close proximity, then the sensor will not detect the temperature. The body temperature is continuously monitored and plotted in the serial plotter as shown in Fig. 9.

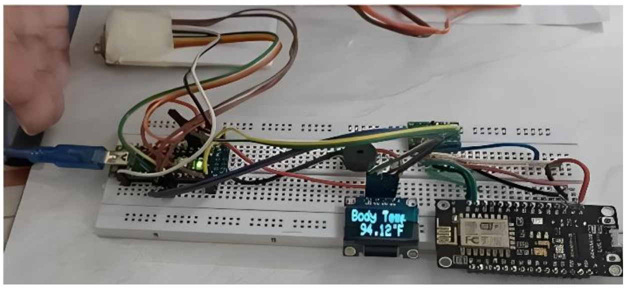

Figure 8. MLX90614 IR temperature detects the body temperature and displays it in OLED.

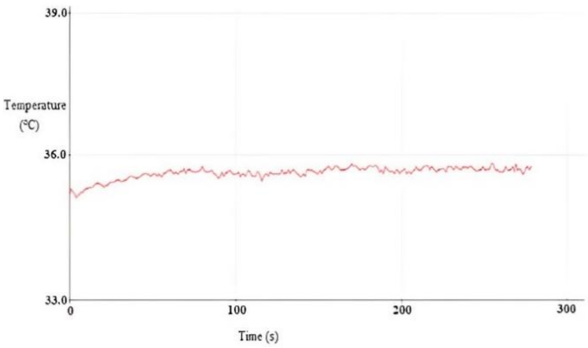

Figure 9. Graphical output of temperature sensor plotted in the serial plotter.

During experimentation, the body temperature of different persons is measured using this device and recorded. The actual body temperature of those persons is also measured using the standard device and results are noted. The performance of the developed prototype is validated by comparing the results obtained using this device against the results from standard measurement and is represented in Table III.

TABLE III. TEMPERATURE MEASUREMENT OF DIFFERENT PERSONS

Person Number	Measured Temperature (T_m in ºF)	Actual Temperature (T_a in ºF)	Relative error (%)
1	97.17	98.1	0.948
2	96.2	97.04	0.865
3	97.02	97.9	0.898
4	94.12	95.03	0.957
5	95.2	95.8	0.626
6	94.07	95.2	1.186
7	96.1	96.8	0.723
8	97.2	98.01	0.826
9	95.5	96.2	0.727
10	96.7	97.3	0.616

The relative error in measurement using this device is calculated using the following Eq. (2).

$$Relative\ Error\ (\%) = \frac{T_a - T_m}{T_a} \times 100 \quad (2)$$

where T_a is the actual value of temperature measured using a standard device and T_m is the measured value of temperature using the prototype. An average relative error of 0.837 % is observed while measuring the temperature using this developed device.

C. Measurement of Glucose Level

The glucose level of diabetic patients needs to be checked frequently as the deviation in glucose level may trigger serious health issues. Regular monitoring of glucose levels by invasive methods causes pain and infection in the patients which is not a feasible method in the long run. Hence, a non-invasive method of glucose level monitoring would be apt for diabetic patients to check their glucose level at home with much cost effectively. The range of sugar levels for persons with different health conditions prescribed by the American Diabetes Association (ADA) is given in Table IV [25]. This value can be used as a prime reference value for comparison of their glucose levels measured at home. This prototype developed using an IR sensor of transmittance type for glucose level monitoring is tested experimentally with five persons. The glucose levels of the persons are measured after having food by keeping their fingers over the IR sensor individually. To detect their actual glucose levels at that instant, a standard pricking-type glucometer is used for measurement. The observed values of glucose levels obtained from both methods are plotted in Fig. 10. From the graph, it is observed that the measured values lie in the prescribed range of glucose levels for normal persons after food. The average relative error in the measurement of blood glucose level using this device as compared to the standard invasive method is 9.48 %. The sample output of glucose level detected experimentally in real time of a person after 3 hours of lunch is shown in Fig. 11. It displays the glucose level to be 115 mg/dL on the OLED screen.

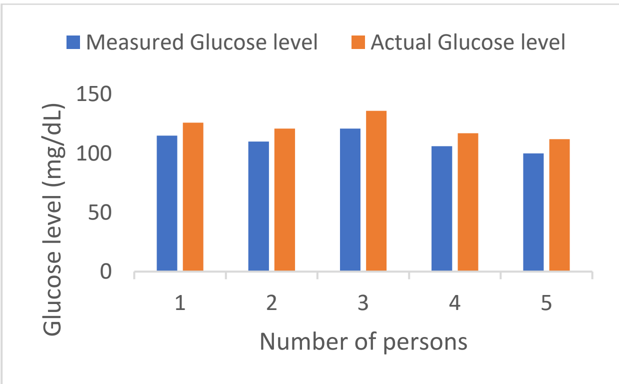

Figure 10. Glucose level of different persons measured after 3 hours of food using IR sensor and standard glucometer.

A single prototype capable of measuring multiple body parameters by non–invasive technique is achieved in this work. As mentioned in the literature, most of the existing works use individual devices for addressing every individual parameter. To monitor the basic parameters like temperature, blood glucose level, heart rate and blood oxygen saturation level at home, this preliminary device could be used and thereby it reduces the cost incurred in procuring multiple devices for measurement. The performance of the prototype is proved by comparing the results obtained using this work with the existing works and is presented in Table V. An average relative error of 0.93 % is observed in SpO_2 measurement using our device whereas the error is 1.59 % in the existing work [13]. Similarly, in the measurement of blood glucose level, a 9.48 % error is observed which is very less compared to the error of 13.36 % as reported in the reference [9]. Finally, in the temperature measurement, the average relative error is 0.837 % which is almost in the same range as that of the reference work [14].

TABLE IV. BLOOD SUGAR LEVEL CHART [25]

Health condition	Sugar level in mg/dL		
	Fasting	Just after food	3 hours after having food
Normal	80-100	170-200	120-140
Pre-diabetic	101-125	190-230	140-160
Diabetic	> 126	220-300	> 200

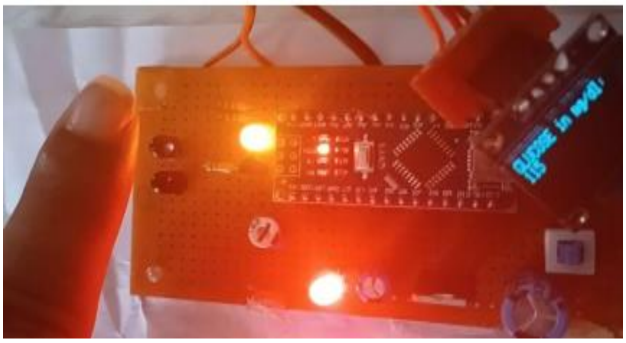

Figure 11. Glucose level measured using IR sensor is displayed in OLED.

TABLE V. PERFORMANCE COMPARISON WITH THE EXISTING WORKS

Parameters	Average Accuracy in (%)		Reference number
	This work	Existing work	
Blood Oxygen saturation level (SpO2)	99.07	98.41	[13]
Blood Glucose level	90.52	86.64	[9]
Temperature Measurement	99.2	99.6	[14]

V. CONCLUSION

A prototype of a smart non-invasive multiple physiological parameter monitoring systems has been developed and presented in this paper. This system can be utilized as a preliminary monitoring device to detect the heart rate, blood oxygen saturation, glucose level and body temperature with close approximation to the actual value. Since this system adopts non-invasive technology, it features painless measurement, free from infection, quick and easy usage of devices available at low cost. The continuously monitored data has been stored in the cloud and also made available to the Doctors through the Blynk App. In case of abnormal health conditions detected in the report, the health advisor can instantly provide necessary treatment to the patients.

The non-invasive blood glucose level measurement implemented in this research work resulted in an average relative error of 9.48 % which is comparatively lesser than the existing work. But, the deviation in measurement could be still reduced by developing an accurate sensing system in future. Also, a cardiac sensor can be integrated along with this setup, so that a cardiac pulse waveform can also be observed which will be helpful for people with heart problems. This prototype can be made as a wearable device in near future so that it can be used as a portable device for preliminary health monitoring at home.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Sathya P. and Rajalakshmi S. are involved in conceptualization, conduction of research and analyzing the data. Sathya P has written the paper and Rajalakshmi S made the proof reading and editing of the paper; all authors had approved the final version.

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