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Design of Low Cost IoT Assisted Remote Health Monitoring System for Diabetes

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Abstract

The human race world over has been facing unprecedented challenges of pandemics with viral and bacterial microorganism mutations. One such unprecedented virus outbreak over last few years was Coronavirus disease (COVID) which completely changed human perceptions and global response mechanism for such kind of future possibilities. It is of infectious nature and caused by the SARS-CoV2 virus. This virus first emerged in humans in China and quickly spread to other countries, affecting human existence throughout the world. The whole of humanity including engineers, scientists, and medical professionals joined forces to fight against this virus. Although the collective efforts succeeded in controlling the outbreak ultimately but the capacity of virus to quickly evolve and change its variants sustained its various mutations. Further, the restricted movement of people to stop the spread of COVID personal visits to the medical practitioners got affected severely. This further affected people with ailments like diabetes and studies have shown that diabetic people are more severely affected by the COVID. The large number of diabetic people worldwide has necessitated the continuous monitoring of patients through remote monitoring mechanisms using invasive and non-invasive methods of measuring sugar levels. Invasive glucose monitoring involves risk of infection at home. This paper presents the scheme for remote health monitoring of the diabetic patients with non-invasively methods coupled with internet of things (IoT) mechanism to assess glucose levels, heart rate and oxygen levels so that the information can be relayed to medical expert at remote location. The level of glucose is measured using PPG (photoplethysmography) signals.

Keywords: IoT, Remote health care monitoring system, Blood glucose sensor, Cloud storage, Non-invasive sensing, Biomedical.

1. Introduction

In this fast-moving world, time seems to slow down as COVID-19 has made a drastic impact on human life on earth. This coupled with lifestyle diseases like diabetes, which are spreading rapidly compared to their earlier phases are deteriorating the health of the people worldwide. Slowly, these lifestyle diseases have changed forms and have turned into hereditary diseases as well. When it comes to the chronic diseases of mankind, diabetes is at the forefront affecting billions of people world over [1, 2]. Diabetes is classified as a disease that has immune disorders, genetic factors, lifestyle and many other factors responsible for its occurrence. Diabetes is classified mainly in two types: type 1 and type 2. In type 1 diabetes, the amount of insulin secreted falls below the required level, but in type 2 diabetes, the body becomes inefficient at utilising even the present level of insulin with decreased sensitivity of the body to insulin levels [3]. More than 90% of the human population suffering from diabetes belongs to the type 2 diabetes category. The number of people affected is increasing alarmingly and rapidly without any check. According to the standards set by the World Health Organisation (W.H.O), a healthy person has a fasting blood glucose level between 3.9 and 6.1 mmol/L and a blood glucose level after 2 hours of eating of 7.8 mmol/L or less [4]. The most used method to measure the blood sugar level is to take a blood sample from the human body by pricking the fingertip. Pricking the body every time to know about blood glucose level is a process that is painful and causes stress; hence, research work is going on with various techniques to monitor the blood glucose level of the human body by non-invasive methods. Following are some of the non-invasive methods that, based on detection techniques, detect glucose levels in the body [3,4].

- Optics
- Microwave
- Electrochemistry

There are ongoing research efforts on methods to make the non-invasive glucose monitoring system the norm in the whole world. From the various techniques of spectroscopy, infrared based method is the one that is least affected by various operational conditions, including physical conditions. The change in the blood volume flowing in the body is measured by the infrared sensor used in the system to calculate the blood glucose level of the human body [5]. The combination of non-invasive techniques to measure the blood glucose level of the human body and advanced IoT technology, a path-breaking miraculous system can be formed to continuously monitor the level of glucose in the blood. The use of optical signal which is processed to get various parameters can provide necessary health parameter data which can be made available to a doctor or medical service provider who might be at a distant place but can monitor the patient in a real-time scenario [6,7]. If the glucose level deviates from the set standard level, an alarm can be generated for the concerned doctors, patient and close relatives of the patient so that recommended precautionary actions can be taken as quickly as possible and further arrangements that may be required can be handled well in time without any delay [8,9]. The continuous monitoring of the health parameters of diabetes patients gets severely affected by the outbreak of Coronavirus disease (COVID) pandemics. Thus, monitoring of large numbers of patients from a distance becomes a necessary requirement that can be fulfilled with the help of modern with internet of things (IoT) based technologies [10-12].

This paper presents a glucose level monitoring system with the help of a non-invasive method using low-cost light emitting and photodiodes coupled with an IoT system for real time remote location measurement. The information that is stored in cloud memory can be accessed by the concerned doctor or medical service provider at a distant place, and real-time action can be taken by them if the values deviate from the standard values.

This paper is structured in seven sections including introduction in section 1. Section 2 and 3 present the system methodology and system design configuration. System operation is discussed in Section 4. Section 5 details the data collection and information storage part. Experimental results and discussion are presented in section 6, followed by conclusions in section 7.

2. System Methodology

The system utilizes IoT based technique for the ease of use at the user end to make things easier without much medical expert help. There are several stages in this system, and it is required that they work in synchronisation to yield the required results according to the continuously varying situations. Microcontrollers like the Arduino or Raspberry Pi can be used to control and synchronize the overall operation of this healthcare system. The information generated from the sensors is further processed and analysed for conclusions. This processed information is displayed on the display unit as well as saved on the cloud storage for historical data preservation. The real-time data can be viewed by concerned doctors or medical service providers for further action according to the prevalent situation [13,14].

The optical detection technique is employed for measuring glucose values. The photo-plethysmography (PPG) method which uses the principle of illuminating certain parts of the body and detecting information about various parameters by gathering the reflected light. There is a direct relation between the PPG data and diabetes. This is reported in literature and the data shows that there is a direct relation between the viscosity of blood and diabetes (sugar level of blood) [3,4]. High viscosity of the blood means a high glucose level, and low viscosity of the blood means a low glucose level, or it can simply be said that the blood glucose level is directly proportional to the blood viscosity. It has been reported in research works that blood flow level is inversely proportional to blood glucose level in the human body [4,5]. The PPG sensor is small in size and can be placed on the fingertip or on the ear, where it can easily sense the blood flow. It is the wavelength of light on which absorption of light by the human body tissues depends. Therefore, near infrared (NIR) and mid infrared (MIR) are best for the purpose of detecting the human body. The near infrared (NIR) has a range of 680 to 2500nm, whereas the mid infrared (MIR) has a range of 2500 to 25000nm. The NIR is more preferred as it has a greater ability to penetrate biofluids as well as soft tissues; it also scatters less in comparison with ultraviolet and visible light. This NIR is therefore better used for sensing as well as measurement in both reflective and transmission methods [15]. Beer Lambert's law talks about the attenuation of light travelling through a uniform medium that contains an absorbing material. According to Beer Lambert's law

$$A = \epsilon * b * c$$

or

$$A = a(m) * b * c \quad (1)$$

where A is measured absorbance, ϵ is molar absorptivity, a(m) is the wavelength-dependent absorptive coefficient, b represents path length of light, and c represents concentration analysed [15].

There is also a relationship between heart rate, oxygen level, and blood sugar in the body. All these parameters can be measured with the help of sensors. If the viscosity of the blood is increased, then it means that the heart rate of the body is decreased. As Poiseuille's law says that heart rate and viscosity of the blood are inversely proportional to each other, this change can be easily monitored with the help of a photo-plethysmography (PPG) sensor [4,5,15].

3. System Design Configuration

The pulse oximeter sensor measures the amount of haemoglobin attached to oxygen molecules. It's sensor Spo2 is used in the design with heart rate sensor. Both are the main sensors used in this system with the Arduino microcontroller as central processing and logic deployment controller. The device is particularly useful in COVID-19 outbreak because the oxygen level in the blood of a person infected with it is usually found to be radically low. Hence an oximeter is already needed to continuously measure the oxygen level of a human suffering from COVID-19. Along with this, the blood sugar level is estimated using the same sensor. Hence, this system has provisions for monitoring oxygen levels, heart rates and blood sugar levels. Figure 1 shows the functional descriptive diagram of the system. Overall, the system is composed of the various sub systems which described in the subsequent subsections.

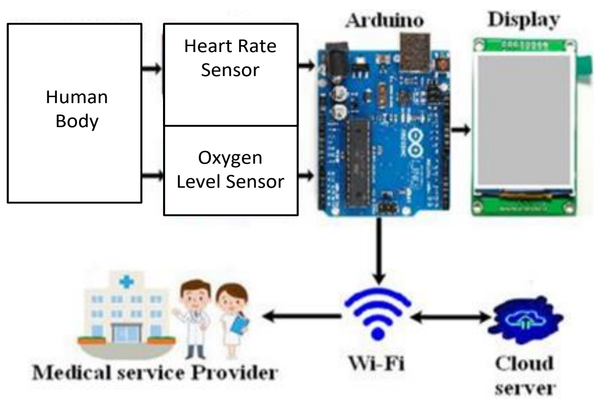

Fig. 1. Functional diagram of the system.

3.1 MAX30102 Sensor Module

It is a powerful particle sensor module that has various LEDs, a photodetector and optical signal processing elements. MAX-30102 is a versatile sensor that can be used for multiple applications. It is a next generation sensor with small size but great precision, making it ideal for portable health applications. The prefixed photodetector provides less chance of the sensor movement during signal detection and a stable signal base with reference is provided. The MAX30102 sensor is easy to attach to various microcontrollers as well. The basic idea behind the working of this sensor is the capture of light emitted by various light emitting devices (LEDs) that comes after passing through obstructions [16]. The photodetector is built in this sensor. This principle is used to detect information about various material or particle presence. The MAX-30102 sensor is shown in Fig.2 below:

Fig. 2. sensor module of MAX30102.

3.2 Arduino Microcontroller

It is a hardware-open board that is very useful for serving various purposes at different levels. Arduino is a compact single-board microcontroller that is very proficient, precise, and fast and cheaper that makes it ideal for such type of healthcare applications. Various software platforms like Python, Linux, etc. can be used to port customized applications on this microcontroller. There are also several other devices that can be added to it like sensors, detectors, etc., which makes it a very versatile tool to develop modern-day devices with tremendous productivity. It is a low power microcontroller [13,14]. It is due to its low cost and versatility that this microcontroller is preferred over other microcontrollers available. The Arduino platform is shown in Fig. 3.

Fig. 3. Arduino microcontroller platform.

3.4 Display Unit

The small display unit is used to display the information generated to the user. The liquid crystal display is deployed in the system, which is power-efficient and very slim in size, which is helpful in maintaining the compactness of the system. The display unit is shown in Fig. 4.

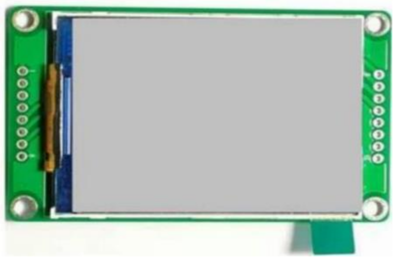

Fig. 4. System display unit.

4. System Operation

The system is highly capable of controlling various operational stages simultaneously, and the success of the system depends on how well various stages of the system work in collaboration with each other. The sensor module generates a PPG signal, which is attached to the Arduino which processes the provided data and transmits the data to a cloud server, from where the doctor or medical service provider can also monitor the parameters and take quick action according to the present situation. The quickness of the action is the main factor when it comes to saving a person's life and this factor is the major determinant in the success of the remote health monitoring system-based treatment. During an emergency, this quick treatment can be lifesaving as well.

There is a display attached to the device, from which the current parameter can also be viewed by the patient. The collection of data is one of the important steps that determines how well the system is going to perform. The sensor collecting data is highly advanced and has data format flexibility in its usage along with reliable data. This data is gathered by the Arduino microcontroller and further processed. The Arduino handles the task of synchronizing and managing different stages of the system simultaneously. The power on which this system works is standard portable device voltage level of 5 volts and 1 amp. The maximum estimated power used is approximately 5 watts, which is very low and good for a longer supply life. The sensor also is a low power front end sensing arrangement. Therefore, due to its lower power consumption, this system can be used for a longer duration even by using battery power, which allows it to be used as a portable healthcare devise. This also helps in saving resources as low power is consumed for the working of the system, and the whole unit can be designed to operate on small solar power units as well, which can further help in reduction of resources used. The flow chart of the fundamental system functioning is shown in Fig. 5.

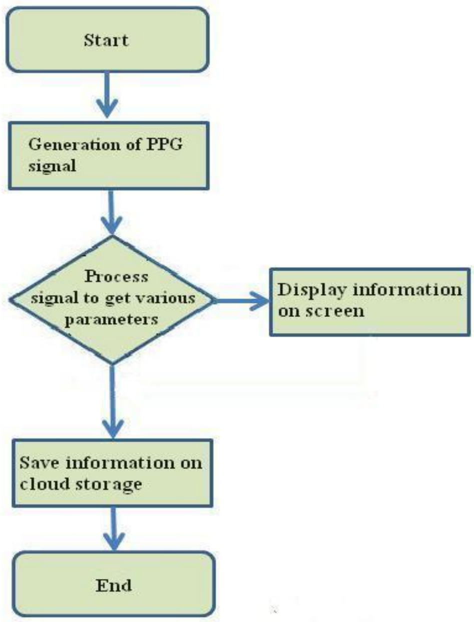

Fig. 5. Flow chart of the system functioning.

5. Data Collection and Information Storage

The sensor used to collect the information is connected to the Arduino, which has a screen to display the information immediately. The information is also stored on cloud storage, where it is available to the doctors or medical service providers concerned with the patient. The 5-volt dc regulated power supply is provided to the controller-sensor system. The sensor is then placed on the human body, from where it sends data to the microcontroller.

The collection of data and integrity is checked in the controller. The MAX 30102 sensor functioning is indicated by the system attached LEDs. The blood glucose level parameter is generated with the help of the processing of data generated with the help of the sensor. The package for MAX 30102 is downloaded and installed for Arduino. Further, Arduino is connected to the sensor MAX 30102, and the Arduino is connected to the display screen as well. The working of the sensor and data generated is checked by placing a hand over the sensor.

After capturing and processing of information/data next important task left is storage of data. The information gathered is saved on cloud storage as next stage, so that the doctor or medical service provider can view the condition of the patient from any location worldwide. The software platform used for this purpose is "Thingspeak". The following steps are used for integrating "Thingspeak" platform with the proposed system:

1. A channel is created on the "Thingspeak" platform by logging in as data and system administrator.
2. The corresponding API key is generated.
3. Required software functionalities are incorporated in the system by the Python generated codes.
4. Code and logic testing is carried out.
5. System output is checked on the display unit.
6. Final verification of the data logged on the Thingspeak database is carried out.

When the data is displayed correctly on online platform, it can be easily accessed anywhere using simple user authentication. Hence data collected with the help of sensors is treated by a microcontroller and sent to cloud storage. From cloud storage, the data is easily accessible to the doctors or medical service providers, and after analysing the data, the doctor can decide on the required appropriate action and timely avoiding any possible emergency.

6. Experimental Results and Discussion

The blood sugar levels for both diabetic and non-diabetic persons are checked with proposed system and results are presented in the Table 1.

Table 1. Glucose level of human body.

Fasting	Person without diabetes	3.9-5.5 mmol/L
	Person with diabetes	4.4-7.2 mmol/L
2 hours after meal	Person without diabetes	7.8 mmol/L
	Person with diabetes	10 mmol/L

The blood sugar level is calculated by the sensor and compared with the invasive device already available on the market. Table 2 below shows the readings taken by the sensor for glucose levels during non-fasting compared with the device available in the market, which is considered as the actual reference value [17-19]. The values that are obtained with the help of the non-invasive system are very close to the values of the invasive device, which is widely used by people. percentage error is also shown in the Table 2. The resultant graph that compares measured values with the actual values is shown in Fig. 6.

Table 2. Comparison table for Glucose level values of body.

Number of Samples	Actual Value	Measured Value	% Error
A1	7.6	7.9	3.95
A2	8.3	8.8	6.02
A3	7.6	7.7	1.32
A4	9.4	9.8	4.26
A5	11.5	11.9	3.48
A6	8.7	9.2	5.75
A7	9.7	9.7	0.00

It is clearly seen from the graph that the difference between measured value and actual value is negligible, so it is observed that the output provided by the system is close enough to the actual values. The heart rate and oxygen level are also measured by the system's sensor and are compared with the devices already available on the market for measuring the heart rate and oxygen level.

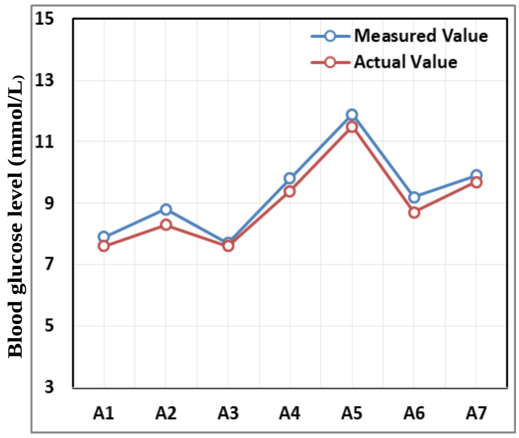

Fig. 6 System measured values and actual values of blood glucose level.

The heart rate is another crucial characteristic that can be used to determine other vital health indicators for the body, and understanding those indicators may provide information about how well the body is operating.

The accuracy of the heart rate sensor is crucial because the heart rate varies for a variety of reasons, some of which may also be linked to certain disorders of the body. Hence it is also a very important health parameter [20]. Table 3 presents the readings taken by the system for heart rate and compared with the device available in the market, which is considered the actual value.

Table 3. Comparison table for heart rate values.

Number of Samples	Actual Value	Measured Value	% Error
B1	68	69	1.47
B2	72	71	-1.39
B3	70	70	0.00
B4	72	73	1.39
B5	69	70	1.45
B6	70	70	0.00
B7	72	71	-1.39

Figure 7 shows the graph that represents the difference between the measured heart rate value and the actual value. From Fig.7, it is clearly observed that the difference between the measured value and the actual value is negligible, and at some places it is overlapping.

It can be concluded that the output provided by the system is similar to the actual value for the heart rate of the body. It can be observed that the measured values are nearly equal to the actual values obtained by the existing device available for measuring the heart rate of the body.

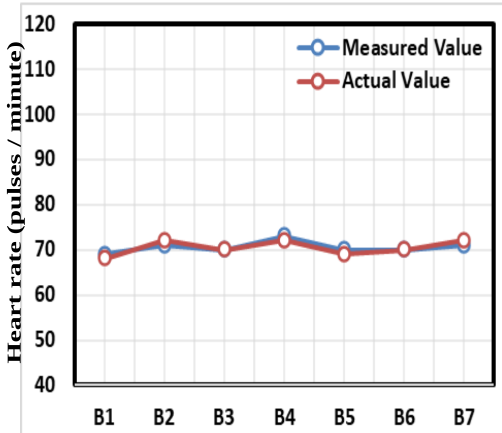

Fig. 7 System measured and actual heart rate values.

Table 4 presents oxygen level data of the body measured by the system and comparison with the oxygen level shown by the existing available. The %age error is estimated by taking the other device readings as actual reference values.

Table 4. Comparison table for oxygen level values.

Number of Samples	Actual Value	Measured Value	% Error
C1	97	98	1.03
C2	98	98	0.00
C3	96	97	1.04
C4	98	99	1.02
C5	97	98	1.03
C6	97	98	1.03
C7	98	98	0.00

The graph that represents the oxygen level variation of measured value from actual value is shown in Fig. 8. It is clearly seen from the graph that the deviation of measured value from actual value is very low, and even overlapping at some places, further showing reduction in average deviation between the two observation sets.

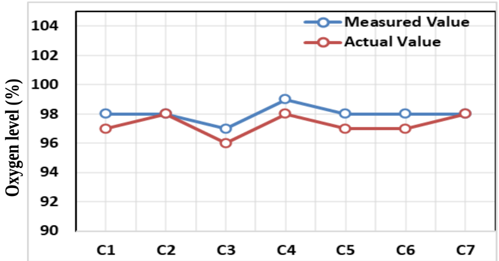

Fig. 8 Graph between measured value and actual value of oxygen level

The measured value for oxygen level with the help of a sensor is almost the same as the oxygen level measured with the help of a device available on the market. This data generated is shown in the display unit as well as on the cloud storage, from where it is available to the doctor or medical service provider at a distant location.

7. Conclusion

This paper presents the concept and design aspects of a low cost, easy to use IoT based scheme for measuring blood sugar level of human body by employing non-invasive methods for remote health care monitoring of diabetes effected patients. The scheme uses optical measurement method and calculates two other essential parameters of heart rate and oxygen level which are necessary parameters in case of any medical emergency. The system is useful in monitoring the health of patient even if the doctor or medical service provider is at a different place that is far away from the patient. Additionally, the routine checkup patient visits to the hospital can be reduced by the proposed technique because essential parameters can be remotely accessed and monitored by the doctor. This helps in adhering to the social distancing norms that are enforced in situations like COVID virus pandemic breakdown. The biggest advantage of this system is utilisation of technology in such a way that people suffering from diabetes don't have to go through the pain of pricking every time to measure the blood glucose level. The risk of infection due to pricking gets reduced, and the enhanced possibility of instantaneous data sharing with doctors is an added advantage of the system. The results that are obtained by the system created for the blood glucose level, heart rate, and oxygen level are close to the results that are obtained by the existing device utilised by the medical service providers. The proposed system with low initial and operating cost helps in extending benefits of the advancements in technology to the lesser privileged strata of the society.

The system functioning can be improved in the future by including additional health parameters without substantially increasing system cost. Another aspect of data security improvement can be improved by further research work on security breaches and data encryption.

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