



# An IoT-Based Non-invasive Diabetics Monitoring System for Crucial Conditions

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**Abstract.** Diabetes is among the major chronic disease around the world since the Glucose level could change drastically and lead to critical conditions reaching to death sometimes. To avoid this, diabetes patient are always advised to track their glucose level at least three times a day. Fingertip pricking - as the traditional method for glucose level tracking - leads patients to be distress and it might infect the skin. In some cases, tracking the glucose level might be a hard job especially if the patient is a child. In this manuscript, we present an optimum solution to this drawback by adopting the Wireless Sensor Network (WSN)-based non-invasive strategies. Near-Infrared (NIR) -as an optical method of the non-invasive technique - has been adopted to help diabetic patients in continuously monitoring their blood without pain. The proposed solution will alert the patients' parents or guardians of their situation when they about to reach critical conditions specially at night by sending alarms and notifications by Short Messages (SMS) along with the patients current location to up to three people.

**Keywords:** Wireless Sensor Network (WSN) · Healthcare application · Diabetes · Non-Invasive · Blood glucose · Near Infrared Spectroscopy (NIRS) · IR sensor

## 1 Introduction

Diabetes is one of the major chronic diseases which could lead to different complication and risk to human life [1]. Even though diabetes is not as fatal as other chronic diseases, it could cause a person with a major complex disease like heart disease, stroke, kidney failure and blindness. Diabetes happen when the body either produce insufficient insulin or produce the insulin effectively. For this, the glucose level becomes abnormally high and as a result the patient has to take extra insulin by injection to reduce the glucose level. To control and balance glucose levels in the blood, diabetic patients have to manage their glucose levels throughout the day. Most diabetic patients forced to use the obtrusive technique (prick their finger) at least three times a day to know their glucose level which it always make the patient to be distress and also cause infection of the skin

in the pricked area of the body. Thus, this paper has replaced this method by a non-obtrusive methods that could be comfortable to measure blood glucose levels. As blood is not needed in a non-obtrusive method, the patient does not need to cut their finger every time they want to know their sugar level. It helps a diabetic patient to detect their glucose level, without any pain, distress and being infected with other diseases.

Knowing the hardship of diabetic life living with needles, different people have been trying to replace the obtrusive method with a different kind of non-obtrusive technology i.e. Polarization change, Raman Spectroscopy, Fluorescent spectroscopy, Near-infrared spectroscopy (NIRS), Mid-infrared spectroscopy, Bio-impedance spectroscopy, spit as analytic liquid and warm discharge spectroscopy [2]. Those non-obtrusive technologies replace blood with spit, sweat, skin, eye, fingertip, ear cartilage and others for glucose level detection. In this paper non-obtrusive prototype utilizing NIRS methodology is proposed. NIRS methodology is one of the most painless and comfortable non-invasive blood glucose measuring technology than the others.

Most non-invasive blood glucose detecting technology has to be implemented inside the skin and some of them are made as lenses to put in the eyes. Even though they replace the painful finger pricking method of glucose measuring, the patients don't get comfortable to use them every day. Therefore, as Near-Infrared (NIR) use of intensive light to penetrate the skin and detect glucose level, it will be the most pain-free and promising method of glucose measurement. NIR can penetrate through the skin and detect the glucose level when its range is between 650–1350 nm [3]. It has been used as a sensor that reads the glucose level, by applying them in the thinner part of the body i.e. fingertip, forearm, earlobe etc. NIR gives accurate glucose reading when it applies to the boneless part of our body. NIRS methodology detects the glucose level by placing NIR transmitter radiation of 950 nm from one side of the finger. The other side of the finger places NIR receiver (photo-diode) radiation of 900 nm to receive the attenuated light. The change in the intensity of NIR light received BY the photo-detector after passing through the finger used to detect the amount of glucose level in a person. NIR method have also more advantages in sensitivity, complexity, power consumption, cost, and accuracy than the other non-obtrusive glucose detection methodology.

In this manuscript, we used NIR as a biosensor to detect the glucose level in a diabetic patient. As NIR is pain-free and doesn't cause skin infection, a diabetic patients will be able to wear this device 24/7 h a day in their wrist as watches. The device will be able to detect the glucose level of a person every 30 min or could configure it as a preference when to send the glucose reading. As this device send the glucose reading every 30 min, the patient can detect his glucose before he reaches Hypoglycemia (when blood sugar drops below 4 mmol/L) and Hyperglycemia (when blood sugar is above 11.0 mmol/L two hours after a meal). This device is mostly useful for pediatric age patients because they don't understand when their sugar level starts to drop or go high. Thus, this device will alert the parent by setting the alarm to go off when their child reaches

Hypoglycemia or Hyperglycemia, especially at night. Also, this device will help the parents or guardians to monitor the glucose level of their child remotely when he is away from them. It will start to alert them by sending SMS attaching with the current location of their child if the sugar level of their child starts to drop while he away.

The organization of this manuscript is as follows: Sect. 2 outlines the related works in the area. Section 3 presents the used techniques in this paper as well as the proposed approach and Sect. 4 analyzes the performance evaluation of the proposed approach. Finally, we present the conclusion in Sect. 5.

## 2 Related Works

There is a long history of using sensors in healthcare and medical applications [4–8] and [9]. Sensors can provide patients and their healthcare providers better understanding into the health states that are crucial to detect and diagnose. Recently, we have seen huge innovations in health information technology [10, 11]. The authors in [12] reviewed these technologies in term of health sensing, healthcare data analytics, and the use of cloud computing.

The work in [5] proposed the EPMS which is a WSN-based healthcare monitoring application for epilepsy patients which focused on decreasing the response time for the sudden seizures, protect patients against possible severe consequences and help them become comfortable with the monitoring process. The authors in [13] presented the design and development of a sensor-based system to detect blood glucose non-invasively using NIR radiation using spectroscopic refraction analysis. The authors in [14] and [15] implemented noninvasive blood glucose monitoring device using NIR light which is based on optical transmission and radiation respectively. The work in [16] proposed the IR sensor to detect blood glucose level. In [17], the work proposed a detection system for the glucose level by using infrared light (NIR). In [17], as in [18], the authors proposed mechanisms for detecting glucose level by using infrared light (NIR). In their work they used urine samples instead of blood. The works in [19–21] and [22] adopted the notification properties. In [19], the authors proposed a home fire alarm system that notify the home owners about the fire detection, while in [22], the authors proposed an automatic vehicle accident detection and message sending.

To the best of our knowledge, an IoT-based diabetes detection system that use IR sensors, notify the patients guardians and send the current location of the patients still an open research issue.

## 3 Proposed Solution

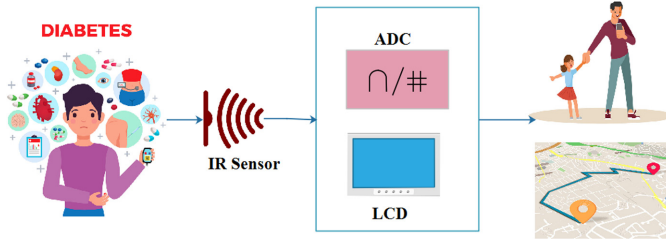
### 3.1 Proposed Approach

There are a lot of non-obtrusive technologies built in order to get over the pain and distress that patients get from the pricking finger method of detecting the

glucose level. NIRS techniques are the most pain free and can detect the glucose without harming the skin. In this manuscript, we use the NIRS method to build a bio-sensor for glucose measuring where the sensor clip is made of NIR LED with 950 nm wavelength in one side of the finger, which penetrate through tissue and attenuates the light signal. The attenuates signal will be received by the photo-diode with 900 nm wavelength in the opposite side of the finger clip, the attenuates light will then converted to voltage after received by the photo-diodes.

The variation in voltage received by photo-diodes will be received as a result for the glucose concentration in the blood which attenuate the transmitted light. The voltage will be filtered and amplified where the amplified signal will then be changed to analog signal and to digital signal by the micro-controller, in order to be read by the electronic devices. When the result of the glucose level display on the LCD, the micro-controller will differentiate it according to the amount of glucose. When the result is in normal level, it will just show the result with no notifications.

Once the results reach certain amount, the buzzer will turn on and the GSM will send SMS message attaching location by the GPS module to the person mobile phone. Figure 1 represents the proposed model.

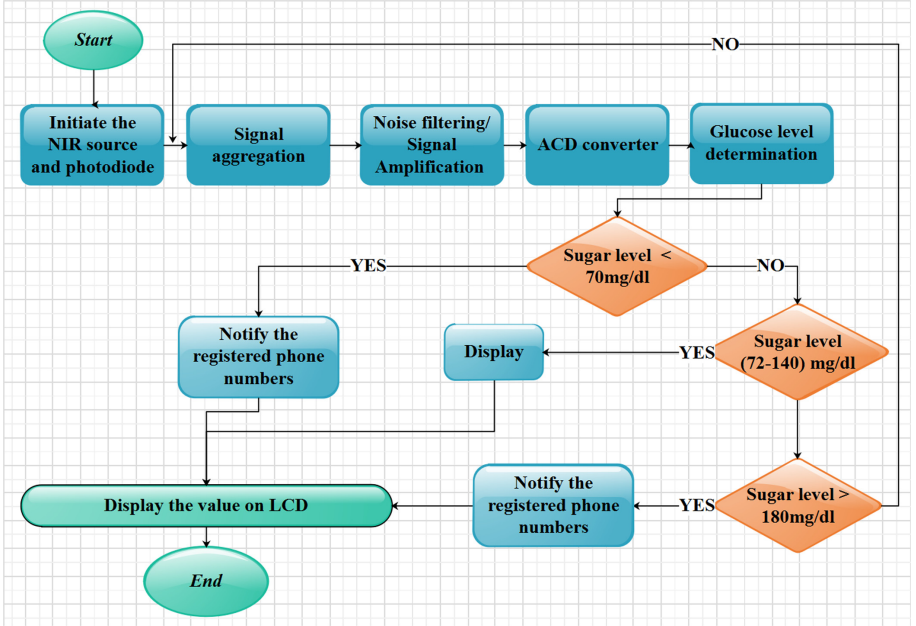


**Fig. 1.** IoT-based diabetic patient monitoring system

Figure 2 shows the overview of this project, when the fingertip sample pass between the NIR LED and photo-diode the system will detect the glucose value. It then determine how to react according to the glucose level result. Whether to send an alert message to the registered numbers or not.

**Table 1.** Notations used in tested methods

Notation	Description
$I$	Light Intensity
$I_0$	Incident light intensity
$L$	Optical path length
$\mu_{eff}$	Effective attenuation coefficient



**Fig. 2.** The flowchart of the proposed IoT-based diabetics monitoring system

This manuscript worked based on the absorbance of light through different objects. As Beer-Lambert Law is based on absorbance measurement [23], this law plays a big role in this manuscript. Beer-Lambert Law states that absorbance of light through any solution is in proportion with the concentration of the solution and the length path traveled by the light ray [23]. In this project, we try to pass the light through fingertip. When light passes through fingertip it can be observed and scattered by tissue. The amount of glucose level in blood will affect the amount of light either observed or scattered in the tissue. Light attenuation theory [24] describes as represented in Eq. 1:

$$I = I_0 * e^{-\mu_{eff} * L} \quad (1)$$

where  $I$ ,  $I_0$ , and  $L$  refer to light intensity, incident light intensity, and optical path length inside the tissue respectively. The Attenuation of light inside the tissue depends on the  $\mu$  coefficient which refers to the effective attenuation coefficient ( $\mu_{eff}$ ) is given as presented in Eq. 2:

$$\mu_{eff} = [3 * \mu_s(\mu_s + \mu'_s)]^{\frac{1}{2}} \quad (2)$$

Therefore, this equation can tell us based on the scattered light, the glucose concentration in blood.

## 4 Performance Evaluation

### 4.1 Simulation Settings

The simulation settings are presented in Table 2.

This project use one sensor which is the IR Sensor - to measure the glucose level in blood by infrared radiation. The patient have to put his fingertip not farther than 0.1 cm from the sensor in order to read the exact measurement of glucose level. The device will take 5 s to display the result on the LCD as well as 7 s to send the SMS attaching with current location of the patient when the reading meet critical condition. The buzzer noise could be heard in a range of 500 X 500 m. The communication range between the device and the SMS message sending, cover every range inside local communication.

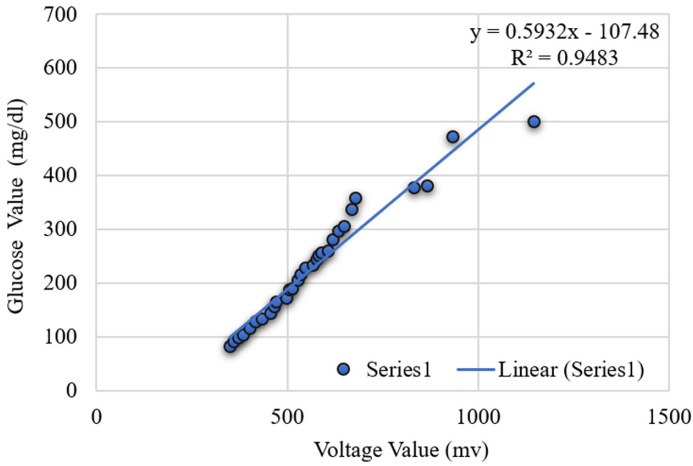
**Table 2.** Simulation settings

Simulation inputs	Input value
Number of sensors	1
Displaying result on LCD	5 s
Range of sensor	0.1 cm
Simulation time	5 s
Sending SMS and location	7 s
Range of communication	Everywhere (Etisalat range)
Communication range	0.1 cm
Operational area	200 m x 200 m
Routing protocol	DSR
Showing result	Every 30 min
Packet size	250 bytes

### 4.2 Tested Scenarios

A sample of 30 diabetic patients have been considered in the test. First we test the glucose reading of the patients by the glucometer (pricking fingertip) method and collect the readings. The proposed model has been used to test the voltage reading of the same patients' sugar level. The glucose reading of the patients have been predicted by the proposed system. Table 3 presents the collected readings.

By considering the data in Table 3, we use the polynomial regression method in MS Excel to track whether there is correlation between the voltage reading and glucose reading or not as shown in Fig. 3.



**Fig. 3.** Correlation between voltage and glucose readings

All the data collected from the voltage reading in non-invasive method and glucose reading in invasive method shows that there is a correlation between them, as shown in the regression analysis in Fig. 3. This study help us to predict the glucose concentration by using the polynomial regression analysis and equation applied in the data-set. Thus, the voltage reading received by the photodiode when the fingertip placed will be sent to the micro-controller to be calculated as glucose reading. When the micro-controller receive analog voltage, it will calculate and display it as glucose reading in the LCD.

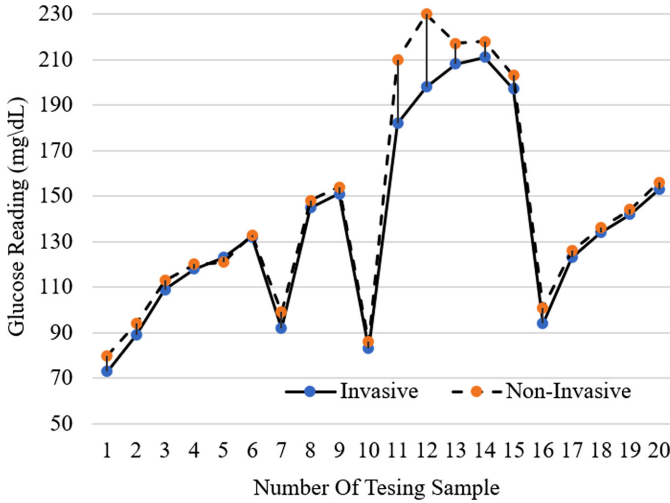
The relation between the glucose concentration results come from the invasive and non-invasive as shown in Fig. 4.

Table 4 presents the glucose reading between the invasive and non-invasive method.

In this project, we have done three testing method to find out the more accurate one.

### 1. First Scenario

A person in normal condition which is between 4.0 to 5.4 mmol/L (72 to 99 mg/dL) when fasting up to 7.8 mmol/L (140 mg/dL) 2 hours after eating. When the person put his finger on the sensor, after 5 s the system will display the result in the LCD. No further action will be taken by the system, when a person is in this condition.



**Fig. 4.** The relation between the glucose concentration results received from the invasive and non-invasive

**2. Second Scenario**

Hyperglycemia when a person above 180 to 200 mg per deciliter (mg/dL), or 10 to 11 millimoles per liter (mmol/L). When the system display the glucose level in LCD, after 3s the alarm will be on. It will continue making noise for about 1 min. Also, immediately after 4s of the alarm on, the SMS attaching with the current location will be send to the registered numbers of the responsible persons.

**3. Third Scenario**

Hypoglycemia when a person reach a level below 3.9 mmol/L (70 mg/dL). When the person put his finger on the sensor, after 5 s the system will display the result in the LCD. After this, the system will take the same action that taken with the second scenario.

**4.3 Results Analysis**

For the invasive method to measure the glucose level we use the glucometer. And for the non-invasive method of detecting glucose level the person have to place his finger tip on the sensor. We perform for about 20 times, in both the invasive and non-invasive method of detecting.

Figure 5 presents the Bar graph chart that compare the accuracy of the glucose detected by the proposed non-invasive system with the value detected by using the invasive method.

To know in which scenario the system give the more accurate value, we try several times with three of them. When a person is in normal condition, the system give the most accurate value. As shown in the chart, we take the average value from all the sample values. For the normal condition, we got average value

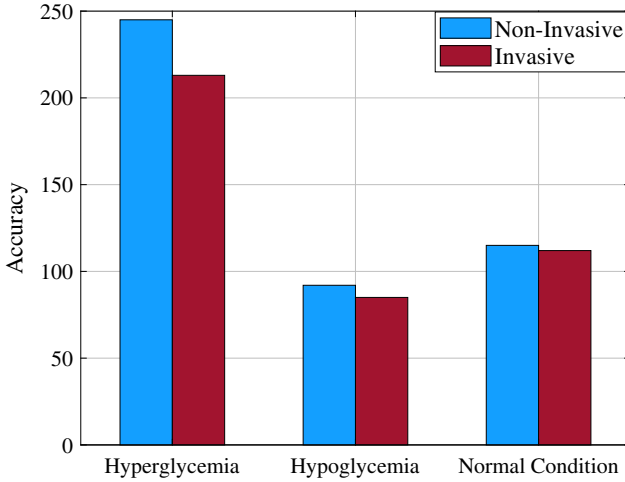
115 mg/dL in non-invasive and 112 mg/dL in invasive method. Which the difference between the average values are +3, most accurate value from the other two. Also, as shown in the graph, for hyperglycemia condition we got average value 245 mg/dL in non-invasive and 213 mg/dL in invasive. Which the difference between the two average value is +32, less accurate of all. For the hypoglycemia the average value difference is 92 mg/dL for non-invasive and 85 mg/dL in invasive, which the difference is +7. Thus, in hyperglycemia and hypoglycemia the system difference was a bit greater. Therefore, the system give most accurate value when the person is in normal condition.

**Table 3.** Voltage and glucose readings using the invasive method

No	Voltage reading	Glucose reading	No	Voltage reading	Glucose reading	No	Voltage reading	Glucose reading
1	350	83	11	499	172	21	608	261
2	361	92	12	506	189	22	619	282
3	372	99	13	514	190	23	634	297
4	384	105	14	528	205	24	649	305
5	401	116	15	536	216	25	668	337
6	416	128	16	549	228	26	679	359
7	435	134	17	568	234	27	833	377
8	457	145	18	577	244	28	868	381
9	466	157	19	583	251	29	934	472
10	472	166	20	591	257	30	1146	501

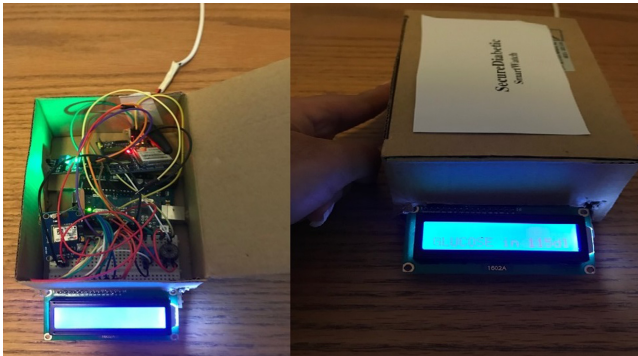
**Table 4.** Invasive and Non-Invasive methods comparison

No	Invasive method	Non-invasive method	No	Invasive method	Non-invasive method
1	73	80	11	182	210
2	89	94	12	198	230
3	109	112	13	208	217
4	118	120	14	211	218
5	123	121	15	197	203
6	133	133	16	94	101
7	92	99	17	123	126
8	145	146	18	134	136
9	151	153	19	142	144
10	85	88	20	153	156



**Fig. 5.** Accuracy comparison of glucose detected by the proposed non-invasive system with the value detected by using the invasive method

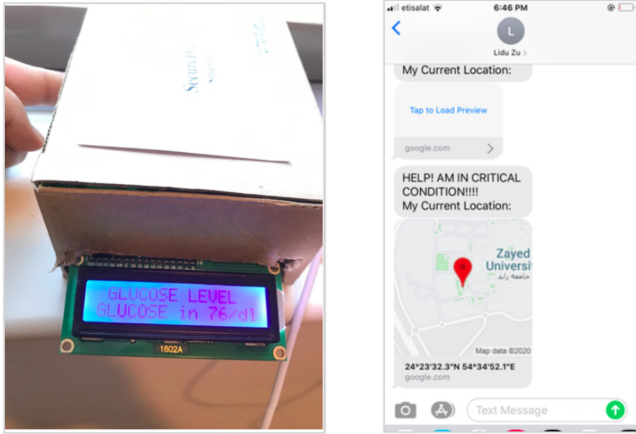
Figure 6 Shows the developed non-invasive sensing module used for testing. When a person place his finger on the sensor, the result will come as voltage reading in Arduino Uno. When the value is displayed on the LCD, it will show as glucose reading.



**Fig. 6.** Developed module

Figure 7 shows an example in which when a person place his finger on the sensor, the LCD is showing that the glucose level is 76 mg/dl which means that the glucose level of this person is about to reach Hypoglycemia (when a person glucose level reach below 3.9 mmol/L (70 mg/dL). Thus, the device will alert the parents by making noise along with sending alert SMS messages attaching the

patient current location to the registered number. The same caution messages will be sent when the person reach hyperglycemia.



**Fig. 7.** The module work

## 5 Conclusion

Diabetic is a simple chronic disease if we know how to manage our glucose level. This manuscript will help diabetic patients, particularly the paediatric age patients, to monitor their glucose level continuously and alert their guardian in critical condition. Most diabetic patients use the traditional technique (pricking finger) to know their glucose level which is painful, stressful and uncomfortable. In this paper the non-invasive method using IR sensor which is pain-free technique has been proposed for continuous glucose monitoring in which the ray emitted by the IR LED has pass through the skin and observe the glucose level by the photo-diode. The glucose level will then be displayed on the LCD as well as it send alert messages when the glucose level meet hypo or hyperglycemia. Finally, SMS by GSM Module along with GPS location will then be sent to the responsible person, when the glucose level reach a certain level. The manuscript prove that the usage of the proposed non-invasive mechanism performs with the highest accuracy along with the shortest response time.

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