Design and Development of Infrared LED Based Non Invasive Blood Glucometer

Komal Lawand[1]
Department of Instrumentation Engineering
Ramrao Adik Institute of Technology.
Navi Mumbai, India
komal.lawand@gmail.com[1]

Mahesh Parihar[2], Shital N.Patil[3]
Department of Instrumentation Engineering
Ramrao Adik Institute of Technology.
Navi Mumbai, India
parihar.rait@gmail.com[2]

***Abstract*— Diabetes affects more than 285 million people globally according to estimates by the International Diabetes Federation (IDF). It is a metabolic pathological condition of concern, which affects vital organs of body if not diagnosed and treated on time. Regular monitoring of blood glucose is important to avoid further complication. Commonly used glucose measurement methods are invasive which generally involve finger puncturing. These methods are painful and frequent pricking cause calluses on the skin. It also has a risk of spreading infectious diseases if the needle is contaminated or used more than once. Therefore there is a need to develop a non-invasive monitoring system which can measure blood glucose continuously without posing much problem and easy to use for the diabetic population. In this paper, near infrared optical measurement is applied to overcome the invasive method drawbacks like frequent puncturing, high recurring consumable cost and danger of spreading infectious diseases. The designed device consists of an infrared LED having a wavelength of 900 to 1100 nm as emitter which placed over the fingertip for measurement of blood glucose optically. The intensity of received light depends on the glucose concentration present in blood. The signal is then amplified and fed as input to microcontroller Arduino uno for displaying glucose signal on a computer after carrying out Regression analysis. By analyzing the variation in voltages received after reflection of incident light in the cases the approximate glucose level of the individual is going to be predicted. A compact framework for non-invasive blood glucose measurement has been designed and tested successfully. The results obtained were validated by using various statistical techniques like standard deviation, standard error, percentage linearity etc. It is found that statistical analysis gives correlation coefficient of 0.93. The result obtained shows that voltage intensity level due to pulsatile nature of blood flow and blood glucose level has correlation.**

Keywords—Diabetes, Non invasive, NIR, Intensity, Regression

I. Introduction

Diabetes mellitus is a disease in which the body does not produce sufficient insulin and represent one of the major health problems in society. The World Health Organization estimated that there will be 177 million who suffered diabetes in 2000[1]. Commonly seen as somewhat trivial as compared to heart diseases or cancer, diabetes can lead to kidney failure, blindness, and amputation. In 2030, diabetes is predicted to be the 7th leading cause of death in the world. In available market available glucometers are invasive. Diabetic patients need to monitor their blood glucose two to three times a day.

A recent studies have indicated that the health risks associated with diabetes are significantly reduced when the blood glucose level are well and frequently controlled. Thus, having proper monitoring at home or work is important. At present, the common existing methods of blood glucose monitoring require obtaining a blood sample by pricking a fingertip with a needle. These methods sometimes discourage the patient to take the test because the procedure is invasive [2].

Non-invasive methods of monitoring blood glucose level are more superior to the current invasive method. Nowadays, a portable and non-invasive glucose meter is highly demanded by the society. There are many approaches on designing non-invasive glucose meter. Towards this one of the designs is by using near infrared method using finger probe and it is safe as there is no direct electrical contact between the patient and the device. The concentration of glucose in the blood is calculated based on the scattering and absorption of light through the blood. The level of the concentration is displayed on the LCD.

Optical method is more trustworthy, cost effective and popular method for glucose measurement [4]. To provide non invasive measurement approach is analyzed. In addition to near infrared method, there are a variety of the optical methods for the non-invasive technique like Raman's spectroscopy, photo acoustic spectroscopy, polarization technique, polarimetry and light scattering[5][6].

So, developing a non invasive way of measuring blood glucose would be much more convenient from the end user prospective. The aid from irritation and unease due to frequent finger pricks and reduction in medical waste would be the main advantages of non invasive glucose meter. Non invasive analysis of the glucose minimizes all the above troubles involved and hence cut down the healthcare cost [7].

This paper introduces a possible design and development of a sensor based system to detect blood glucose non-invasively using Near-infrared (NIR) radiation using spectroscopic refection analysis. It describes the principle of glucose measurement using NIR method. Designing of the system involves the defining the hardware and software requirements consisting of Arduino microcontroller, IDE software and

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computer. The processing is done by the microcontroller and the level of glucose will be displayed on the computer. The hardware part also consists of Infrared Light Emitting Diode (IR LED), a photodiode sensor, after amplification components and microcontroller. The outputs of photodiode are used to calculate the absorption of light. The signals from the sensor are being amplified to produce high signal to noise ratio (SNR) approximate glucose concentration value is displayed according to difference in the voltage received.

The remaining part of the paper is arranged into different sections. Section II elaborate the designed system architecture and methodology and section III details about the measurement procedure and IV the experimental results and application. In last section conclusion and future developments have been illustrated.

II. System Architecture

After studying research paper [8], near infrared reflection spectroscopy is used in this study. The architecture is divided into several components. The research paper [9] [10] published that, to evaluate and anticipate glucose concentration, it is possible by using glucose spectroscopy between wavelengths 940 nm to 2450 nm. Therefore to setup system for transmission and reception of NIR rays, a reflective optical sensor is used with the fingertip as the body site. The designed system architecture is shown in Fig 1.

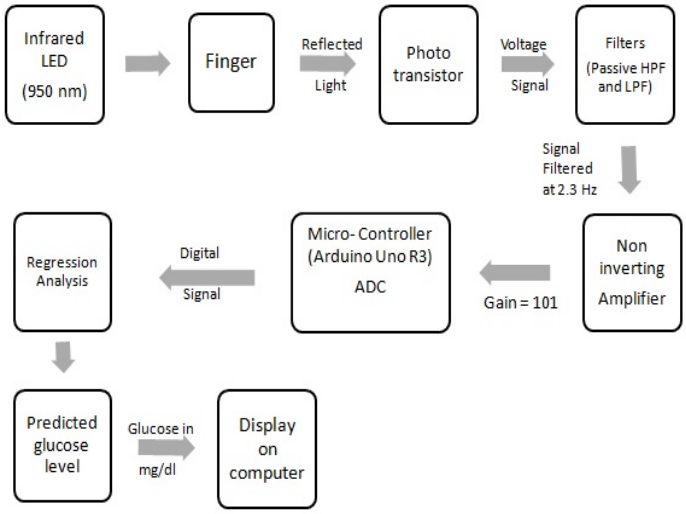

Fig 1: Block Diagram of Designed Method

As shown in above diagram, as light is transmitted by infra red sensor which will fall on finger as we have taken finger as a body site. By reflectance spectroscopy phototransistor will convert reflected light into voltage. This voltage signal is then processed for signal conditioning before feeding into the microcontroller. These signal conditioning parts consist of filters and amplifiers. Analog voltage signal will be filtered at 2.3 Hz by active low pass filter and amplified at the gain of 101. This filtered and amplified signal is fed into microcontroller at analog pin A0 for converting it to digital form to carry out regression analysis. This digital signal is processed at second order regression analysis. This analysis will give predicted glucose value. This glucose value will then be displayed on computer.

III.METHODOLOGY

(A) Electronic circuits

The experimental circuit is set up using near infrared (NIR) spectral range to measure the blood glucose. The data recorded show differences of voltage value related to their blood-glucose alterations [10]. To improve accuracy of the sensor finger cap is made so that other lights will not enter and the designed sensor will give accurate result.

This voltage variation is so feeble and additional signal conditioning stages are necessary to convert it into a recognizable form by microcontroller Arduino uno R3. This signal conditioning part will consist of filtering stage to filter out noise and amplification stage. Next Arduino uno R3 will convert amplified analog voltage to digital value. Regression analysis is also done by microcontroller and predicted glucose value subsequently displayed on computer.

As shown in fig 2, for signal conditioning of the output signal from sensor, operational amplifier IC LM 324 having single supply quad operational amp is selected for this project as it has low input offset voltage (3 mV) and high CMRR (80 dB). Gain of 101 and cut off frequency of 2.5Hz is designed for filter.

For amplification of the sensor signal, non-inverting amplifier is used, having required voltage gain is around 101 and suitable higher input resistance, by using formula for gain.

$$\text{Voltage gain } A_v = 1 + (R4 / R5) \tag{1}$$

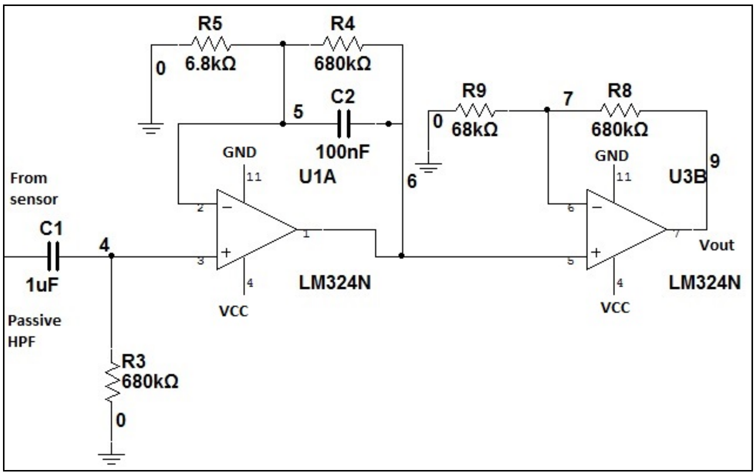

Fig 2: Filter and amplifier circuits

Normal pulse rate of human being is varied between 60 to 180 pulses per min. Therefore considered low pass filter of cut off frequency 1Hz to 3 Hz is designed to remove high frequency components and 50Hz power line interference. High pass filter of cut off frequency 0.5 Hz is used to remove baseline drift or low frequency signals and it is given by

$$\text{Cut off frequency } F_c = 1/ (2\pi * R4 * C2) \tag{2}$$

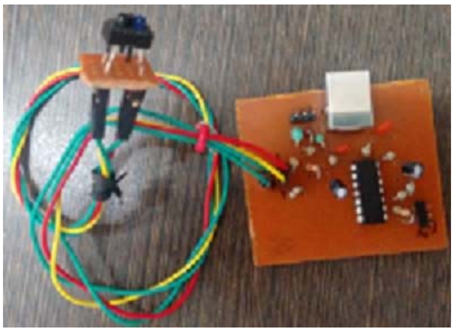

Fig 3: Sensor integrated with electronic circuit

The second stage is non inverting amplifier with the gain of 101.Output voltage is connected for the data acquisition by interfacing to computer by Arduino uno R3. Arduino uno R3 is a microcontroller board based on the Atmega 328 having 14 digital input/output pins, 6 analog pins, 16 MHz crystal oscillator, a USB connection, a power jack, and reset button. This circuit is also simulated using Proteus software before it is actually implemented on hardware.

(B) Software requirement of the system:

Software required for this microcontroller is Arduino 1.0.6. It's an open-source physical computing platform based on a simple microcontroller board, and a development environment for writing software for the board. The open-source Arduino Software (IDE) Integrated development environment makes it easy to write code and upload it to the board.

Flowchart of the system:

Step1: Initialize hardware and software by connecting Arduino microcontroller and PCB to the PC.

Step 2: Serial monitor will display message Place the figure on sensor.

Step 3: At analog port A0, microcontroller will read analog voltage as read by sensor.

Step 4: Convert this analog voltage value in to digital value for further processing using in built analog to digital converter.

Step 5: If the calculated value is less than thresholds go back to loop or step 2.

Step 6: If not then by using this voltage value and regression analysis by using look up table predict the glucose value.

Step7: Display the predicted glucose value on the serial print of computer

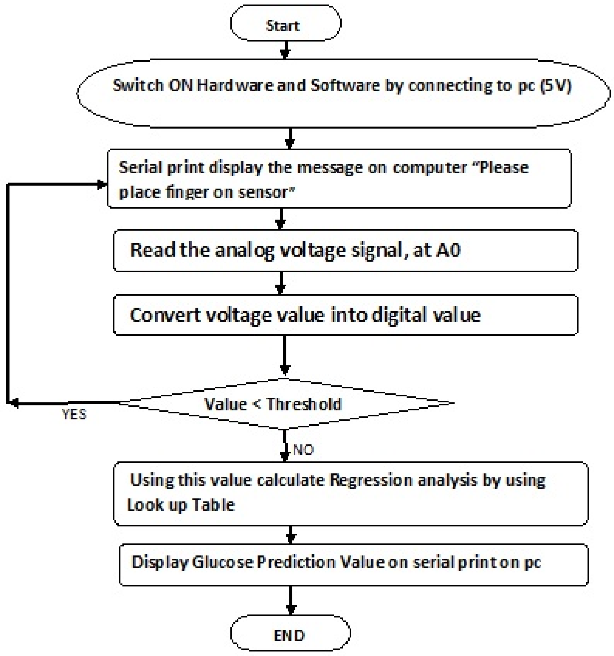

Fig 4: Flowchart of the designed system

IV. Results

Constructed system determines a method for the prediction of blood-glucose level for human using non invasive methods. It

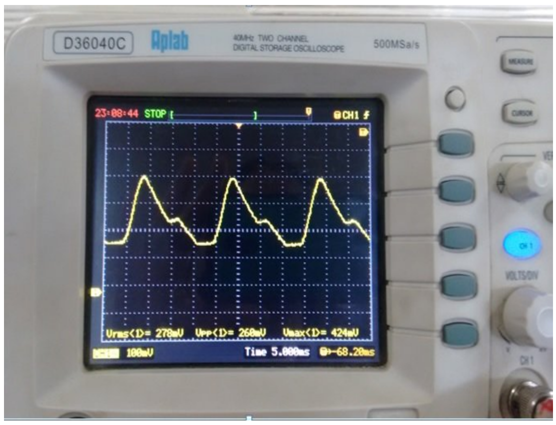

Fig 5: Waveform of pulse signal on oscilloscope

By using this voltage value as X value in regression polynomial, glucose concentration can be predicted. Dataset on sample basis, is formed of six subjects (3male, 3 female) using prick method and voltage value using this method. Using this dataset regression analysis is carried out using MS Excel.

TABLE I: APPROXIMATE VOLTAGE AND PREDICTED GLUCOSE VALUE

Voltage value (V)	Glucose value(mg/dl)
1.1	67
1.2	70
1.3	69
1.4	68
1.5	79
1.8	80
1.9	80

By using above table we can find out the second order polynomial regression analysis as mentioned in equation no 3. This equation is used to measure the glucose value in real time [voltage intensity]

$$y = 1.8375x^2 + 18.945x + 41.288 \quad (3)$$

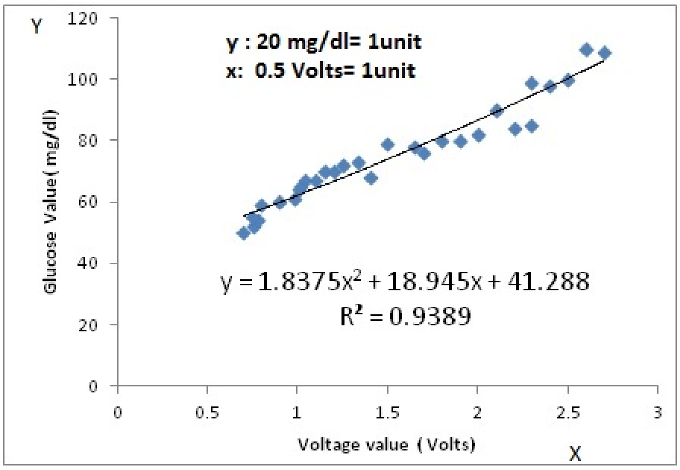

Fig 6: Regression analysis of glucose data with voltage

This work provides an innovative idea to solve the existing problems like painful pricking, high recurring cost and danger of spreading infectious diseases while pricking. The data obtained from intensity variation study shows that there exists a correlation between the variation in voltage intensity and glucose level. By using the regression analysis and polynomial equation relation between voltage value and glucose concentrations, glucose concentration to be measured by this method are predicted in the following table. Results are tabulated and statistical analysis is done for validation of this estimation of the glucose concentration. Table represents glucose concentration estimated using designed method and prick method for 5 subjects.

TABLE II: GLUCOSE CONCENTRATION BY DESIGNED AND PRICK METHOD

Sr no.	Glucose concentration by designed method (mg/dl)	Glucose concentration by prick method (mg/dl)
1.	74	68
2.	75	72
3.	84	75
4.	80	85
5.	84	90

Glucose concentration by designed and prick method is then plotted in this graph using MS Excel.

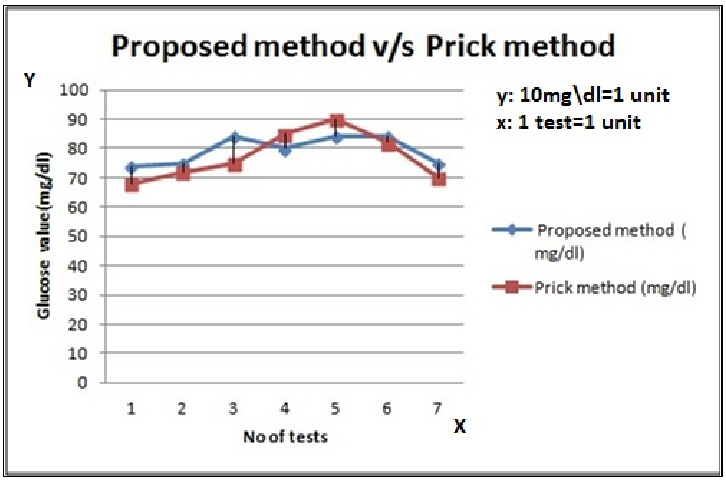

Fig7: Designed Method v/s Prick Method

By using result we can analyze the designed method by calculating percentage error and variance and sensitivity, processing gain, unprocessed and processed SNR of the designed method.

1. Percent Error

Glucose concentration by designed method and prick method is tabulated and percentage error is calculated by using following formula.

Percentage error = [(Measured value – Actual value)/ Actual value]*100 (4)

TABLE III: CALCULATION OF PERCENTAGE ERROR

Sr No.	Glucose concentration by designed method (mg/dl)	Glucose concentration by prick method (mg/dl)	Percentage Error
1.	74	68	8.82
2.	75	72	4.16
3.	84	75	6.67
4.	80	85	-5.88
5.	84	90	-6.67
Mean	79.42	77.42	2.47

As shown in the table it can be interpreted that designed system gives +8 % to -8 % percentage errors. On an average it gives less than 3% Percentage error. Therefore we can interpret that designed method predict glucose value close to the prick method. Also this error can further be minimized if the larger data set of glucose levels of many no of person are used in the table no 3.

2. Sensitivity

Sensitivity can be predicated from the slope of the graph. If a line has a positive slope then y always increases when x increases and y always decreases when x decreases due to linear relation between y and x.

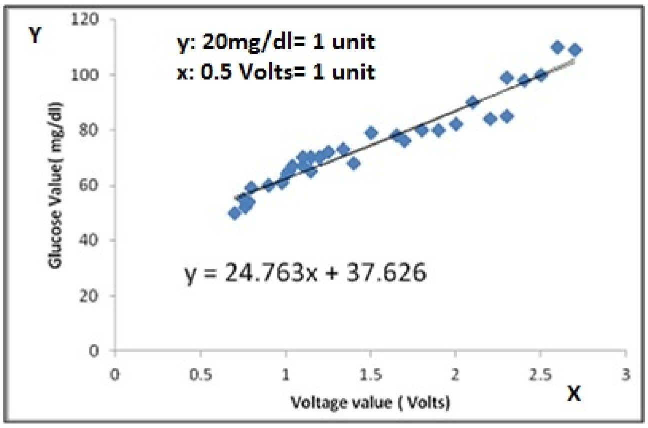

Fig 8: Measure of Slope for sensitivity estimation

As shown in the above figure 8, slope of glucose value against voltage is determined from the graph & found to be 24.76. Therefore as slope value is positive, we can interpret that as voltage value is increasing glucose value is also increasing. The result obtained shows that blood flow has proportionate corelation to blood glucose level.

3. Processed and Unprocessed Signal to Noise ratio and Processing Gain

Processing gain is given by the ratio of the signal-to-noise ratio of a processed signal to the signal to- noise ratio of the unprocessed signal. This parameter gives the value of processing gain and SNR Value of the system when it is processed and unprocessed. Signal processing gain is usually expressed in dB[12]. For designed method processing gain is calculated using following equation.

$$\text{Processed SNR} = 20\log(Vin/(Vn/\sqrt{N})) \tag{5}$$

$$=20\log(20mv/(20mv/\sqrt{700}))=20.5 \text{ dB}$$

$$\text{Unprocessed SNR} = 20\log(Vin/Vn) \tag{6}$$

$$=20 \log(20mv/50mv)= -7.8 \text{ dB}$$

where Vin(Signal)= 20mV, Vn(Noise level)= 50 mV.

$$\text{Processing gain} = \text{Processed SNR} - \text{Unprocessed SNR} \tag{7}$$

From the result it can be seen that processed SNR is more than Unprocessed SNR and therfore we can intepret that processing of signal is carried out with 20.50 - (-7.8) = 28.3 dB of processing gain. Hence, we can say that this system is processing the signal with the gain of 28.3 dB.

4. Standard Deviation and variance

Standard deviation is a measure that is used to quantify the amount of variation or dispersion of a set of data values from a suitable reference.

TABLE IV: STANDARD DEVIATION AND VARIANCE

Sr no.	Design method	Prick method	Design method	Prick method	Design method	Prick method
1.	68	75	74	78	74	72
2.	70	70	72	79	75	72
3.	72	74	78	80	77	75
4.	74	76	79	77	72	76
5.	75	75	80	75	78	74
Mean	71.8	74	76.6	77.8	75.2	73.8
Std. dev	2.86	2.34	3.43	1.92	2.38	1.78
Variance	8.2	5.5	11.8	3.7	5.7	3.2

From the table, it can be concluded that standard deviation of predicted glucose values is changing from 2.8 to 3.43 whereas for prick method it's changing from 1.92 to 2.34. Therefore we can interpret that predicted glucose values are close to the mean and expected value approaching towards better instrument performance characteristics.

5. Standard Error

As shown in following table standard error is calculated, which gives the error in predicted values over expected value. Based on three different data sets glucose prediction for first case is 71.8 +/-3.01 mg/dl and for other its 76.6 +/-3.32 standard error. Therefore we can interpret that predicted glucose value is within +/- 5 deviated from the accepted values.

TABLE V: STANDARD ERROR

Sr no.	Design Method	Prick method	Design Method	Prick method	Design Method	Prick method
1.	68	75	74	78	74	72
2.	70	70	72	79	75	72
3.	72	74	78	80	77	75
4.	74	76	79	77	72	76
5.	75	75	80	75	78	74
Mean	71.8	74	76.6	77.8	75.2	73.8
Std. error	3.01		3.32		2.74	

6. Percentage linearity

As shown in fig 9, the graph of voltage value as sensor output v/s Predicted Glucose value, correlation coefficient is to be 0.9342. As square of R is coming close to 1, therefore we can interpret that this establishes stronger linear relationship between predicted glucose concentration from non invasive method and voltage value from sensor output.

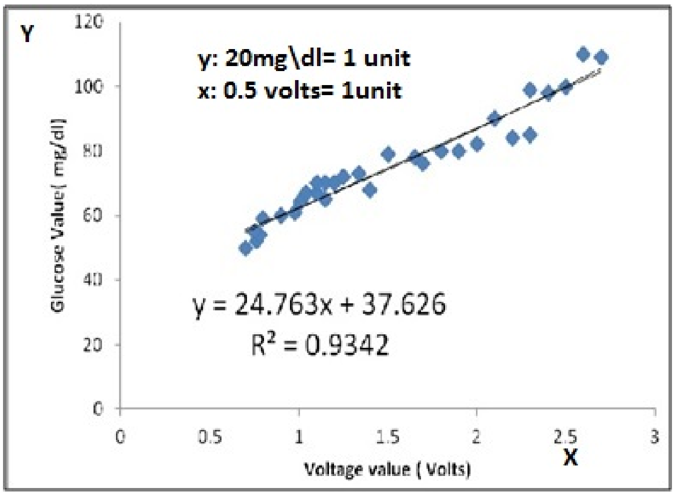

Fig 9: Measure of linearity of sensor

Therefore as tabulated above statistical parameters like percentage error, standard error, linearity, processed SNR, unprocessed SNR, processing gain, standard deviation and variance, we can interpret that designed non-invasive glucometer system is validated using these analysis. Also it can be concluded that it shows the correlation between voltage intensity and glucose values. From the analysis done, the results obtained shows that as the glucose meter reading increases the standard deviation corresponding is decreasing and it gets closer to the expected value. This aids in establishing the stronger linear relationship between predicted glucose and voltage value.

CONCLUSION

We have designed and implemented the idea using reflection spectroscopic method for non- invasive measurement of blood glucose level which offers several advantages, such as absence of pain and exposure to sharp objects, the potential for increased frequency of testing and tighter control of the glucose concentration and lower cost. We have been able to determine cardiac related pulsatile voltage changes, using regression analysis for glucose and subsequently been able to predict the blood estimates non -invasively. In this prototype of device developed, wavelength of 950 nm obtained using NIR sensor and finger as a body site is used for predicting blood glucose level for the healthy adults. A low cost framework for non-invasive blood glucose measurement has been designed and implemented on printed circuit board and results are validated using different statistical methods. This statistical result analysis of the designed system with the prick method gives less than 10 % of percentage error and is within acceptable accuracy. The obtained results show that correlation coefficient is between cardiac related pulsatile voltage intensity and glucose value is 0.9342 and therefore we can conclude that there exist relationship between the predicted glucose and voltage value from the sensor.

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