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Design and Implementation of an NIR-Technique Based Non-Invasive Glucometer using Microcontroller

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ABSTRACT

Diabetes is called the major contributors to all types of major diseases and if the patients are not taken care of properly then eventually it causes to death. However, this is a non-contagious disease. This disease occurs when glucose level in the blood increases above a threshold value. Therefore, regular determination of blood glucose level is a pre-requisite to take care of diabetic patients. Existing techniques for determination of blood glucose level are invasive techniques based on needles which are inserted into human body to take blood sample out of the body and then it is passed to the disposable test strips for processing chemically to determine the amount glucose present there. However, to alleviate the pain of the patient and use of test strips of these techniques have led to the development of non-invasive techniques. These techniques use near infrared sensor for glucose level determination from fingertip without requiring needles and test strips. Near infrared (NIR) optical signal is transmitted through one side of the fingertip and then received from its other side through which blood glucose's molecular count is predicted by analyzing the variation in the received signal's intensity after its reflection and this data can wirelessly be transmitted to a remote PC through the use of IoT. In this work, we have developed such as system using microcontroller and other electronic parts. Before that we developed a simulation model in Proteus environment. After hardware implementation of the device, we measured glucose levels of several persons having different age levels using our designed meter and the conventional invasive method based meter. We found out that the average percentages of deviations are very small (5.15%) which prove that our designed meter is working very well.

Keywords: Diabetes, NIR-Technique, Non-Invasive, Glucometer, Microcontroller

1. INTRODUCTION

The term blood sugar means the amount of glucose in blood per unit volume. Usually, it is represented in milli moles per liter (mmol/L) or milli grams per deciliter (mg/dL). The standard range of blood sugar level in human beings is from 4.5 to 6.5 mmol/L. In healthy person, because of the human body's homeostatic mechanism of blood sugar regulation, the blood sugar level restores to a range of approximately from 4.4 to 6.1 mmol/L. The glucose level of blood may increase momentarily after taking meals up to 7.8 mmol/L in non-diabetic person [1]. According to the American Diabetes Association, the glucose level of blood should be from 5.0 to 7.2 mmol/L before meals and less than 10 mmol/L after meals for diabetic person. Higher or lower values of blood sugar levels than this range results diabetic in human body and this is, in fact, may cause a serious health hazards. Therefore, proper detection of blood sugar level is needed accurately without giving much discomfort to the patients.

The tormenting proliferation of the diabetic patients in the whole world has become a great problem now. If the patients can't be diagnosed at the early stage and regular monitoring of blood glucose levels can't be done properly then it would cause a serious problem for all. Besides, if the patients can detect the disease and its level by him/herself then it would reduce the burden on the health professionals too. However, many patients are reluctant to use needle based machines due to pain and health hazard.

Therefore, the clinically effective method is to use the noninvasive technology based blood glucose levels monitoring and hence its regulations. Non-invasive techniques are being used in many biomedical applications [2-3].

On the other hand, the microcontroller based system is inexpensive, small in size and user friendly. In several automatic biomedical measurement and monitoring systems and devices, microcontrollers are being widely utilized [4-6]. Therefore, this paper describes how a critically necessary blood glucose machines can be designed and developed based on the non-invasive method and microcontroller technology. It will reduce the cost when commercialized in the market, will eliminate pains of the patients, and will provide accurate readings of blood glucose detection capabilities. The results obtained using the noninvasive blood glucose detection technique are very encouraging when satisfactory when it is compared to that of the conventional needle based invasive methods.

One of the foremost health issues that are being confronted by the current world is diabetes or diabetes mellitus. It is a kind of metabolic ailment in which case the blood glucose level fluctuates from its normal range of 4.0-7.8 mmol/L [7]. If the glucose level goes beyond this range it may affect the major organs of human body if proper treatment is not provided in time. Therefore, early and accurate detection of glucose level is necessary. Once a person is detected with diabetes he/she should be brought under regular monitoring of his/her blood glucose level and this is imperative to shun further impediments and to maintain a healthy life. In developed country, patients who want to monitor their blood glucose level at home usually purchase an electronic glucometer. However, to monitor blood glucose level, there are two widely used methods, such as, invasive and non-invasive methods. In invasive method, a patient needs to perforate his body part, usually in the fingertip to take a blood sample. But this method causes pain and anxiety. Sometimes, this procedure may create infections by the needles being used. On the other hand, non-invasive blood glucose level there is neither pain nor any anxiety as in this method no needles are used, only reflected infra-red light from the finger tips are taken to determine the glucose level of the blood [1-3].

Therefore, the objectives of this research are to-

i. study non-invasive techniques in blood glucose level measurement
ii. develop a simulation model for NIR-technique based glucometer
iii. design and implement an non-invasive technique (infra-red) based blood glucose level measurement system
iv. measure and analyze the blood glucose level data
v. minimize such kind of device

2. LITERATURE REVIEWS

Before designing the non-invasive glucometer, we studied several literatures available in several journals and conference proceedings. Many university researchers and commercial industries are taking initiatives to devise near-infrared spectroscopy based method to determine the blood glucose level. On the other hand, many people are working on near-infrared diffused reflectance based method, some are using transmittance and refraction of visible laser light based technique, some are using mm-wave based process and so on [8-10].

M. R. Robinson et al. did a preliminary evaluation on the non-Invasive glucose monitoring in diabetic patients using NIR spectroscopy method and they showed the relationship between blood glucose level and NIR spectra for the first time [11].

K. Maruo et al., presented the optical fiber based NIR system. They showed that there is a relationship

between the blood glucose level and NIR spectra and designated that the potential found from NIR spectroscopy can be used to determine blood glucose level non-invasively [12].
Yadav et al. demonstrated that NIR with wavelength of 940nm can be diffused into the forearm and then its reflectance spectra can be measured to find a relationship between the blood glucose level and reflected signal [13].

Haxha et al. also demonstrated an NIR-based system with 940 nm wavelength. But he used transmittance spectroscopy technique found out a relationship between the blood glucose level and transmitted signal [14].

Z. Geng et al. suggested another non-invasive glucose level monitoring method by means of multiple sensors (bio-impedance and humidity sensors) and time series analysis [15].

M. S. Arefin et al. proposed a non-invasive blood glucose concentration detection scheme using a near infra-red light emitting diode having wavelength of 940nm and a photo-detector. They used the diffused reflectance method for this purpose [16].

M. Ahmed et al. introduced an architecture that uses near infrared spectroscopy to determine blood glucose level based on transmittance spectroscopy on the ear lobe. By means of various parameters of human body, like, tissue's thickness and blood's oxygen saturation as well as linear regression based calibration system, an accurate and real-time architecture has been proposed and implemented in a programmable system-on-chip (SoC) having full analog, digital and mixed signal capabilities [17].

B. Javid et al. designed and implemented a noninvasive mobile based system by using optical approaches to quantify the blood glucose and bilirubin levels of a patient. Using a smartphone application, one can communicate through the optical sensor and then display the results. This application can send the necessary information and alert message to the doctor, patient and his/her family members so that proper medical cares can be taken of [18].

In this work, we have developed a noninvasive system using NIR technique, microcontroller and other electronic components. Simulation model is developed in Proteus. Then hardware model is implemented, tested and evaluated.

3. SIMULATION MODEL AND SOFTWARE DEVELOPMENT

3.1 Simulation Model With Proteus

The Proteus Design Suite is an automatic electronic design related software that is being used for research and development type works both in academia and industry. The electronic design engineers and technicians use it to draw the schematic designs for simulation and verification, sketch and test the layouts for electronic printed circuit boards before its manufacturing etc. It can run in the Windows environment. It supports high speed design. It has nearly 800 various types of microcontroller chips to be simulated from the schematic diagram. The microcontroller simulations in Proteus environment works by employing either a hex or debug file to the microcontroller part on the schematic. It is then co-simulated along with any analog and digital electronic circuits coupled to it. Additionally, Arduino microcontroller based circuits can also be simulated in it [19-21]. In such type of environment, our simulation model has been developed as shown in Fig. 1.

The simulation model has been designed in Proteus before going into the implementation stage of our research. After the completion of model design we simulated our system. The designed circuit is shown in Fig. 1. In the figure, an input signal value is taken from near infrared sensor by the microcontroller.

Afer that the noise has been removed using the noise filter. Then this value has been filtered out and amplified and connect to an npn transistor for getting the negative value. This signal is connected to the ardinuo's analog port A0. Finally, the output value is displayed in the LCD monitor as shown in Fig. 1.

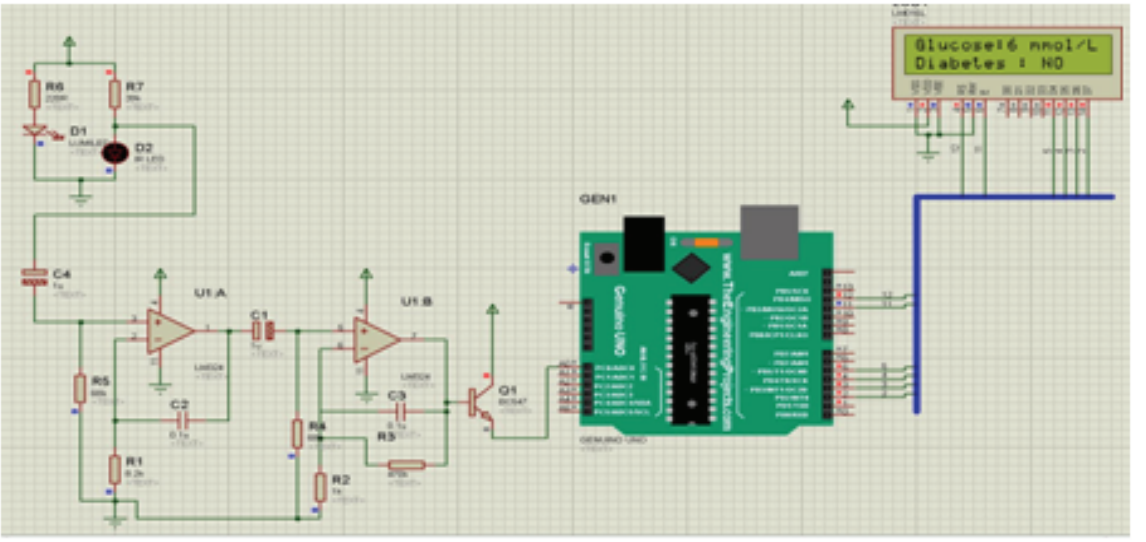

Fig. 1: Simulation Model of the Complete System

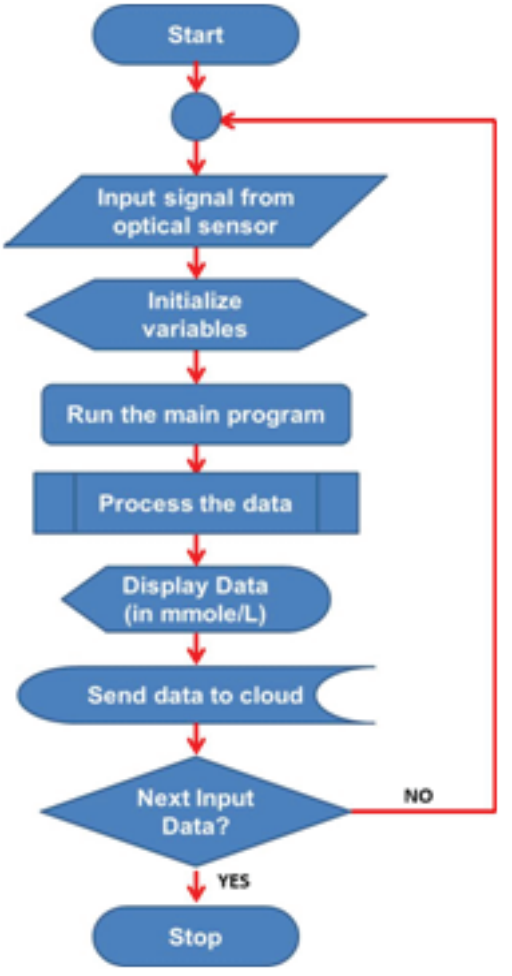

Fig. 2: Flow Chart of the program

4. HARDWARE BASED GLUCOMETER DEVELPOMENT

4.1 Hardware Description

Our country is a developing country. So, we have tried to develop a low cost hardware based device so that the common people can afford this device. In this work, we have used Arduino microcontroller, near infrared LED (NIR-LED) and photodector (NIR-PD) as optical sensors, LCD display, power supply unit etc. to develop the glucometer. We tried to minimize the cost while developing this measuring machine.

The Arduino microcontroller is the heart of the glucometer. This is used for automatic control, calculation and processing of data. A near infra red photodiode/photo-detector which is simply a pn-junction diode that produce electric current by taking the infra-red light signal after reflection from the human body. However, this diode should be operated in reverse biased mode. An infra-red LED is a device that can detect current signal and produce infra-red radiation from it. The LM324 IC has four independent op-amps in it. This is used for voltage amplification with high gain. The main advantage of this IC is that it can be operated from a single power supply and thereby reducing cost of hardware.

4.2 Working Procedures

The near infrared LED and photodector determines the blood glucose concentration. The concentration of glucose in the blood is calculated based on the scattering and absorption of infrared light through the blood. The level of the concentration is displayed on the LCD in appropriate unit.

At first, we insert our finger tip in between the NIR-LED and NIR-PD as shown in the block diagram of Fig. 3. The reflected signal is taken by the NIR-PD. The value obtained from it will be filtered out and then amplified.Then we remove the noise using the noise filter. Again we filtered the signal and amplified it to connect to an npn transistor for getting the negative value and for early showing the value in the LCD display. After that we connect the signal to Ardinuo's analog port A0. Finally, the output value is shown on the LCD display. We can also

why npn transistor & (-) value.

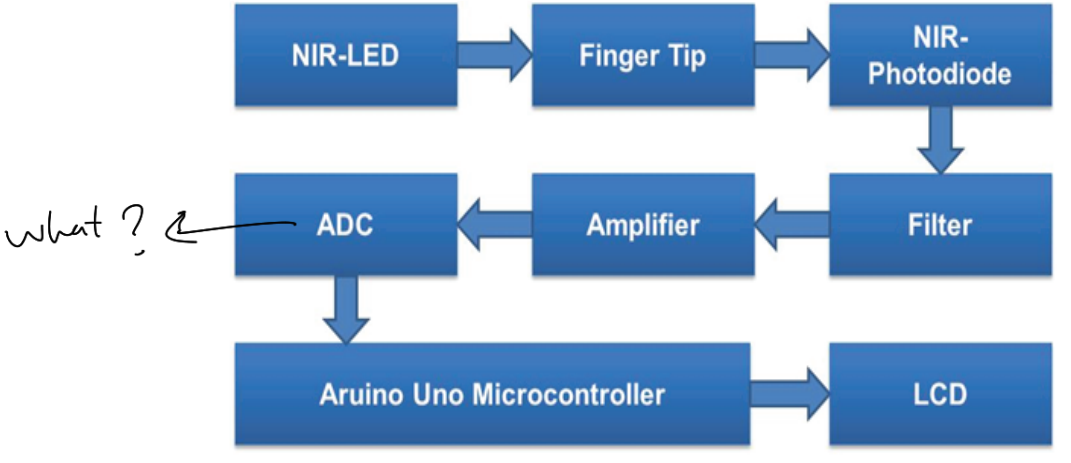

Fig. 3: Block diagram of the complete system

4.3 Printed Circuit Board Design

A Printed Circuit Board (PCB) is used for mechanical support and electrical connections of the electronic components by using various conductive tracks, connecting pads and jumpers. This design is transferred on a copper sheet after various processes like, printing, dripping in a chemical solution, drying, etching, grooving, drilling, cutting, cleaning, laminating etc. A pre-designed conducting copper tracks are created due to these processes on the copper sheet and thus use of wiring is reduced and thereby reducing the faults that could arise due to loose connections of wires. Finally, to place the various electronic components and ICs, one needs to do soldering works on the PCB. Our designed PCB is shown in Fig. 4. The photograph of the developed device is shown in Fig. 5.

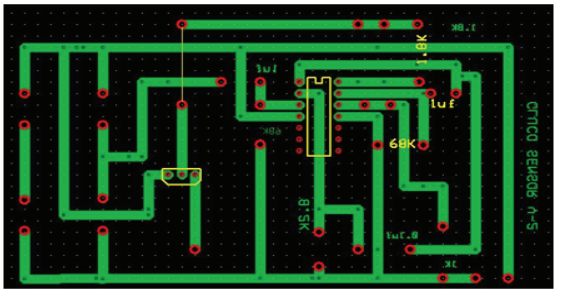

Fig. 4: PCB design of the circuit for hardware implementation

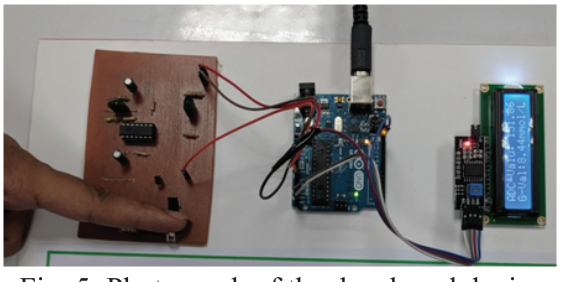

Fig. 5: Photograph of the developed device

4.4 Implementation Expenses

Total prices including price details of various components required to implement the system is shown in Table 1. We see that only BDTK1579 (Bangladeshi Taka fifteen hundred and seventy nine) are required. However, if mass level manufacturing is done then this price would go down drastically. Hence we can say that the implementation cost has been minimized as compared to the existing glucometer machines available in the market.
The non-invasive blood glucose meter's price ranges from BDTK2,200 to TK3500. However, these machines require one time disposable test stripes and needles which has separate cost.

Table 1: Price details of various components

Sl. #	Component Name	Specifications	Quantity	Unit Price (BDTK)	Price (BDTK)
1	Capacitor	1 µF – 50V	2	7	14
2	Capacitor	2 A 104 J	2	10	20
3	Transistor	BC547	1	40	40
4	IC Base	-	1	30	30
5	LM324 IC	-	1	70	70
6	Photo Sensor	Tx & Rx	2	70	140
7	Resistance	1k,10k,120Ω, 5k	10	2	20
8	Cable	-	15	3	45
9	PCB	-	1	300	300
10	Arduino Uno R3	-	1	500	500
11	Display	I2C with 16×2	1	400	400
				Total Price (BDTK)	**1579**

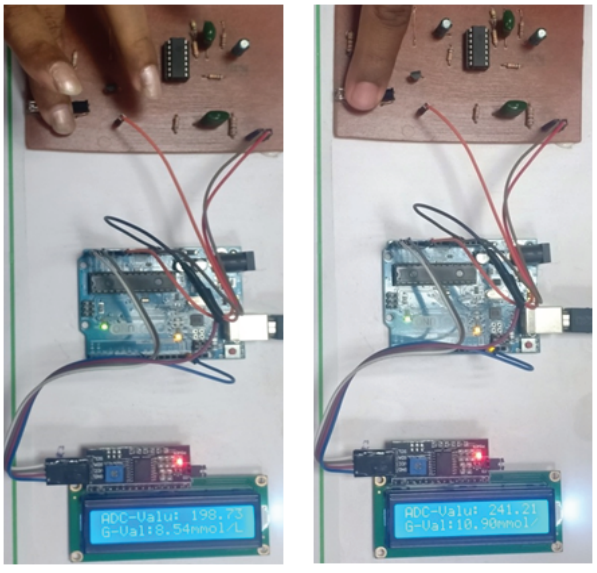

Fig. 6: Samples of Test Data in mmol/L (a) for a young person, (b) for an elderly person

5. RESULTS AND DISSCUSSIONS

Two sample test data displayed on the LCD monitor are shown in Figs. 6 (a & b). In Fig. 6 (a), test data is shown for a young person whose blood sugar value is 8.54 mmol/L as displayed on the LCD screen, and in Fig. 6 (b) test data is shown for an elderly person whose blood sugar value is 10.90 mmol/L as displayed on the LCD screen. Although this is a new idea to measure the blood glucose level in non-invasive technique, it is implemented in hardware. Our research has been focused on to get a new device which will be available at low cost for the developing countries. Finally, this is done and test samples were taken to validate our method and claim the functionality of our designed device. The microprocessor converts the ADC value into glucometer value (in mmol/L) using the following formula:

Glucometer Value = ADC Value/18 – 2.55

They have tried a linear function.

For example, if ADC value is 180 V then Glucometer value will be 180/18 – 2.55 = 7.45 mmol/L.

After this, we plotted the measured ADC values versus the computed ADC values in Volt as shown in Fig. 7. Besides, we compared the NIR-based glucometer values versus the values obtained from conventional glucometer measurements of various patients in mmol/L as shown in Fig. 8. In both the graphs, we see that there is a linear relationship between and as such a little errors are found between the invasive glucometer and non-invasive glucometer samples. That is, average deviations are very small and this proves the validity of our measured data.

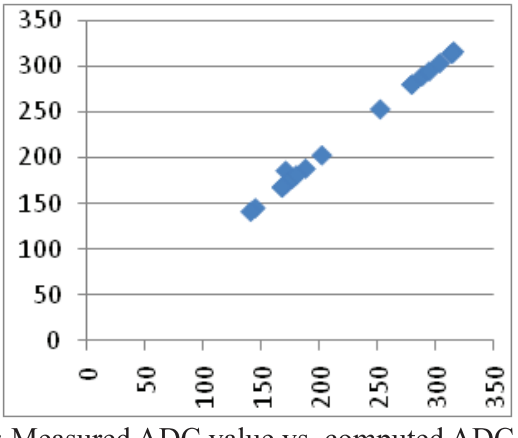

Fig. 7: Measured ADC value vs. computed ADC value

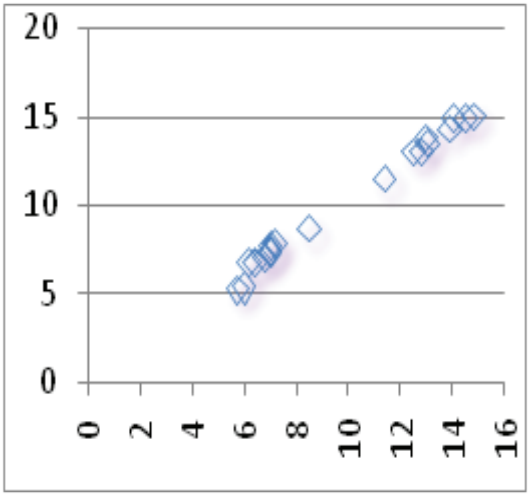

Fig. 8: Conventional glucometer values vs. NIR based glucometer values

Table 2: Comparison of readings of our designed machine and comparative error analysis

Patient	Age (Years)	Conventional Glucometer Reading (mmol/L)	NIR-based Glucometer Reading (mmol/L)	Diabetic Patient (Y/N)	Deviation from Conventional machine (%)
1	47	13.9	14.3	Y	2.88%
2	25	7.0	7.3	N	4.29%
3	42	11.4	11.5	Y	0.88%
4	28	6.0	5.51	N	8.17%
5	20	5.75	5.29	N	8.00%
6	20	6.4	6.75	N	5.47%
7	21	7.2	7.9	N	9.72%
8	20	7.0	7.77	N	11.00%
9	20	7.0	7.5	N	7.14%
10	20	6.8	7.03	N	3.38%
11	40	12.5	13	Y	4.00%
12	40	13.03	13.5	Y	3.61%
13	40	6.3	6.8	N	7.94%
14	45	14.04	14.87	Y	5.91%
15	38	8.5	8.71	Y	2.47%
16	50	14.8	15	Y	1.35%
17	65	12.8	13	Y	1.56%
18	21	6.4	6.8	N	6.25%
19	48	13	13.8	Y	6.15%
20	70	14.5	14.9	Y	2.76%
Average values		9.72	10.06	-	5.15%

In Table 2, we have shown the practical measured data by the conventional glucometer readings in mmol/L and NIR-based glucometer readings in mmol/L for twenty persons with various ages. From the readings, we identified whether the persons under consideration have diabetics or not. We also computed the deviations of the readings by our machine in percentage to that from the conventional machine. This is calculated using the following formula:

$$Percentage\ of\ Deviation = \frac{Conventional\ Glucometer\ reading - NIR\ based\ Glucometer\ reading}{Conventional\ Glucometer\ reading} \times 100\%$$

A sample calculation is shown below for person number 1:

$Percentage\ of\ Deviation = \frac{13.9-14.3}{13.9} \times 100\% = 2.88\%$.

The average deviations were found very small and hence it proves our machines reliability and effectiveness. The expenses were also very low and hence our objectives are attained.

6. CONCLUSIONS

We have attained our objectives successfully by designing and implementing the non-invasive determination of blood glucose concentration. This method has few advantages over the conventional invasive techniques like non-requirement of test stripes and finger-tip penetrating needles, absenteeism of pain etc. This method eliminates fear and anxiety of the patients because in this method, we have used near infrared photo-sensitive electronic components that are non-invasive to count blood glucose level employing diffused reflective scheme. This glucometer is a very low cost device. Therefore, it can be deployed as a medical device in developing countries like Bangladesh. Both the hardware design and software has been made open source. Finally, it was implemented on printed circuit board. The product is used to measure the glucose levels of various diabetic and non-diabetic persons having different age levels. The test results are compared with the test data using needle based methods for the same person and at the same time. Percentage of deviations was computed and it was found that the average values are only about 5%, i.e. within the acceptable accuracy limit. Besides, the obtained results show that there exists a relationship between the non-invasive glucometer value and the analog voltage value from the optical sensor. We took data only on 20 persons. However, to validate the designed and implemented device tests should be conducted on larger population. Besides, software improvement is required to get more accurate results. Application programming interface needs to be developed to provide easy integration of the test data with the cloud through the IoT based system.

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Notes-i

- The method of how the process is done is clear.
- The circuit design is blurred & ADC isn't clear.
- Only 20 patients used so the accuracy of ML model is unacceptable.