# Study on Different Range of NIR Sensor Measurement for Different Concentration of Glucose Solution

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*Abstract*—**The development of noninvasive methods to replace the conventional finger pricking method to measure the blood glucose concentration is developing rapidly. This study was conducted to evaluate different wavelength of near infrared (NIR) sensors that is going to be the best in measuring the glucose concentration samples that was prepared. Three different wavelengths of NIR sensor are used for the testing, 800 nm, 940 nm and 950 nm. Several experiments were conducted to find the relationship between the output voltages and glucose concentration. The results of the experiments proved that the linear relationship between output voltages and glucose concentration is significant for all NIR sensors used and the NIR sensor with a wavelength of 940 nm shows the best fit.**

*Index Terms*—**Diabetes, non-invasive technique, near-infrared sensor, glucose concentration, NIR wavelength.**

## I. INTRODUCTION

Diabetes mellitus is one of the major global issues of public health in the world. Malaysia is ranked number 10th in the world with the highest number of people having diabetes (World Health Organization, (WHO), 2013). This is due to the changes in the human`s lifestyle [1]. There are many factors that cause diabetes to happen. Among of the causes are unhealthy food, smoking, drink alcohol, stress and etc. Diabetes without control and monitoring can cause many effects, complications of health such as heart disease, kidney damage, stroke, and blindness [2]. It is very important to always monitor and check the glucose level in the blood to ensure that it is in a normal range and stable. There is much instrumentation available in the market used to diagnose and monitor blood glucose. The most common method is by pricking the finger. It needs the extraction of blood from the finger [3]. The blood sample will be used to measure the glucose amount using a glucometer. The non-invasive technique is the latest technology that has been introduced as a good alternative compared to blood extraction [4-7]. However, the devices are very costly compared to the finger prick method.

Nowadays, many researchers have been conducted to prove that non-invasive techniques are reliable in measuring glucose level. Various methods have been used such as infrared, photo acoustic, ultrasound, and fluorescence to diagnose glucose amount in the blood [8-12]. Most of the results showed a good correlation between non-invasive and invasive techniques. R. Buda and M. Addi has done a work on noninvasive blood glucose using NIR base and they are using a wavelength of 1550 nm [13].

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## II. METHODOLOGY

The flow chart of the overall measurement process that required for the study is shown in Fig. 1.

The devices to construct is a study based on the suitability and availability of the NIR sensor. Three different wavelengths of NIR sensor and receiver are 800 nm, 940 nm and 950 nm. After selecting the suitable sensor, the placeholder is designed to conduct the experiment so that the glucose solution sample and sensor transmitter and receiver are placed in the holding still in the fixed position.

Then, the conditional circuit is designed so that the transmitter able to emit the maximum power to the receiver. After that, the circuit was tested on the breadboard to troubleshoot and to ensure that the circuit working properly and the output result is in the valid range without saturating before PCB fabrication. Fig. 2. displays the device which consists of an Arduino Uno microcontroller, an LCD, reading stability holder and NIR sensor.

Software development is involving programming on the microcontroller to convert the analog signal to the output that can be understood by the user. Every wavelength used is measured by using various concentrations of glucose solution. The data are collected for analysis.

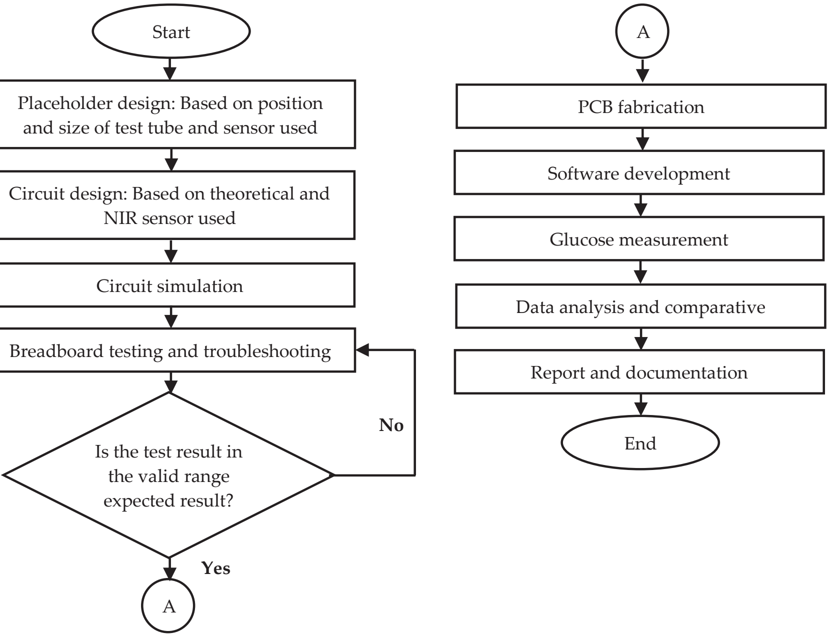



Fig. 1. Flowchart of the experimental process and design

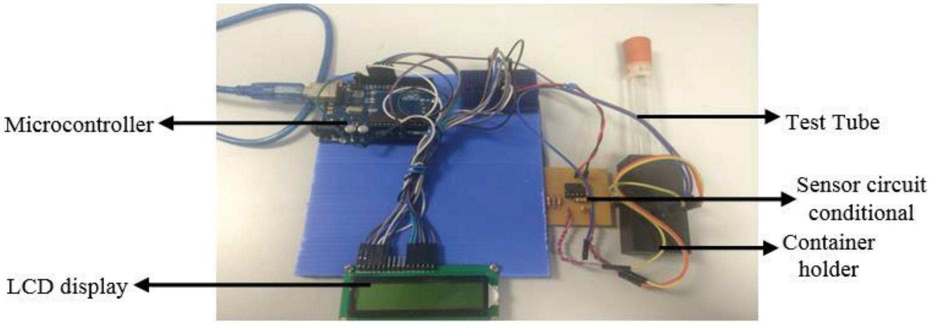



Fig. 2. Glucose Reading Device

*A. System Architecture*

Fig. 3. shows the block diagram of system architecture of the non-invasive glucose monitoring system. The system is operated by transmitting the NIR light to the glucose solution. The receiver, also known as photodiode will detect the absorbance of the light after it has passed through the glucose molecule in the glucose solution. Then the photodiode will convert the signal to an equivalent voltage value. Filter circuit is used to filter noise in the signal detected at the receiver by blocking high frequency. Then the amplifier will amplify the signal to make the signal suitable to read by the microcontroller. The Arduino Uno microcontroller will convert the analog reading to the digital reading and display it to the LCD display.

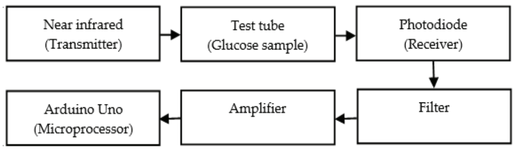



Fig. 3. Block diagram of system architecture

*B. Placeholder Design*

The placeholder is designed using Design Spark Mechanical software. This software is used purposely to design the 3D drawing. After the placeholder had been designed it was fabricated using a 3D printer. The design is based on the position and size of the test tube and NIR sensor. The transmitter and receiver are positioned side by side and focuses on the test tube surface contain a glucose solution. The purpose of the placeholder is to make sure the sensor is in the fixed position during the measurement taken and protect from ambient light sources that can be noise to the output signal. Figure 4 is the design of the placeholder.

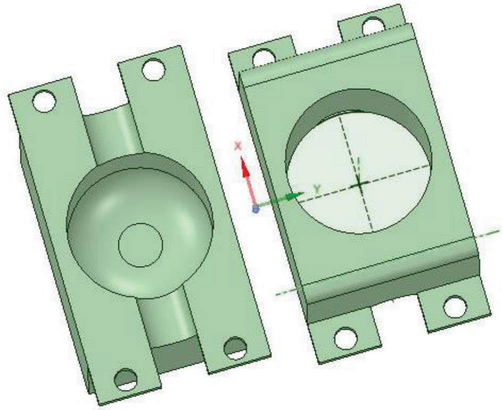
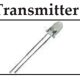
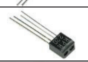


Fig. 4. 3D placeholder design

*C. Circuit Design*

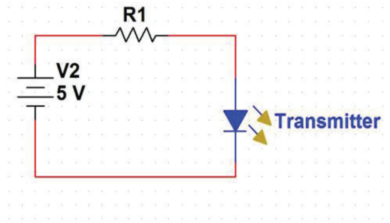
Multisim software is used to simulate the conditional circuit before fabrication. The NIR detection circuit consists of a transmitter circuit and receiver circuit. There are three types of transmitter with different wavelength as can be seen in TABLE I.

TABLE 1. TYPES OF TRANSMITTER USED.

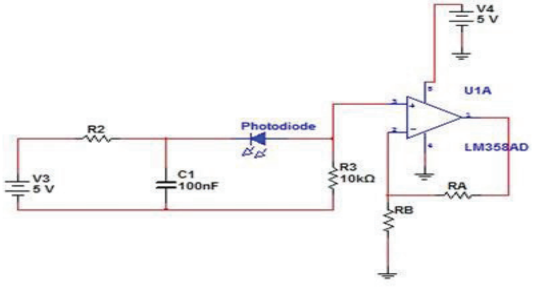
| Transmitter | Type | Wavelength |
|---|---|---|
|  | Transmitter: LTR4206 | 940 nm |
|  | RPR220 | 800 nm |
|  | Transmitter: TEFT4300 | 950 nm |

The receiver circuit consists of a photodiode, a noise filter and operational amplifier. A low pass filter is connected to the voltage source to reduce the noise frequency from the source. The photodiodes that had been used are LTE4206, RPR220, and TSUS4300. This selected photodiodes are suitable with the transmitter as it has a wavelength sensitivity within range 800 nm to 950 nm. The photodiode is used to measure continuous wave of light source and convert the optical power receive from the transmitter to an electric current value. The electrical current is converted into a voltage by placing a load resistor at the anode.

The value of the output voltage is between 0 V to 5 V depending on the intensity of the infrared signal it receives. The output voltages from the photodiode are converted into suitable value and amplify by using operational amplifier. Fig. 4 (a) and (b) is the schematic diagram of the transmitter circuit and receiver circuit.




(a)




(b)

Fig. 5. (a) The transmitter circuit and (b) The receiver circuit

*D. Glucose Concentration Preparation*

Glucose solutions of different concentrations ranging from 50mg/dL–300mg/dL were prepared by dissolving glucose (dextrose monohydrate) as in Equation (1). 20 ml of each glucose solution was transferred into a test tube for measurement. The output of voltages for different glucose concentrations were recorded to determine the relationship between the sensor`s output voltage and glucose concentration.

$$X\ mg/dL = X\ mg\ of\ glucose + 100ml\ of\ distilled\ water \quad (1)$$

## III. RESULT AND DISCUSSION

The glucose concentration from (50 mg/dL – 300 mg/dL) and voltage measurements were obtained from the experiment of the three NIR sensor as shown in Table 2. Results from the experiments show that the output voltages of the sensor increase in direct proportion to increase of glucose concentration. From the output voltage in Table 2, range scale of NIR sensor of 800 nm is larger compared to 940 nm and 950 nm. The range scale for 800 nm is from 2.41V to 4.0V which larger than 940 nm voltage range scale which from 2.3V to 3.45V.

TABLE II. EXPERIMENTAL RESULTS OF OUTPUT VOLTAGES OF THREE DIFFERENT SENSORS PAIR AND DIFFERENT GLUCOSE CONCENTRATION

| Glucose Concentration (mg/dL) | Voltage Output (V) | | |
|---|---|---|---|
| | 800nm | 940nm | 950nm |
| 0 | 2.41 | 2.3 | 0.11 |
| 50 | 3.56 | 2.57 | 0.13 |
| 100 | 3.7 | 2.63 | 0.14 |
| 150 | 3.73 | 2.72 | 0.16 |
| 200 | 3.76 | 2.95 | 0.18 |
| 250 | 3.8 | 3.22 | 0.19 |

From the experimental results, the graph for the three NIR sensor which have a wavelength of 800 nm, 940 nm and 950 nm were plotted to determine the relationship between the two variables, voltages and glucose concentration as shown in Figure 6.

TABLE III. EXPERIMENTAL RESULTS OF OUTPUT VOLTAGES OF THREE DIFFERENT SENSOR PAIRS AND DIFFERENT GLUCOSE CONCENTRATION

| Wavelength | Equation | Regression, $R^2$ |
|---|---|---|
| 800 nm | $y = 0.1896x + 2.8071$ | 0.6059 |
| 940 nm | $y = 0.1811x + 2.11$ | 0.965 |
| 950 nm | $y = 0.0143x + 0.1$ | 0.9615 |

Each of this plot of different wavelength is fitted with three linear equations respectively. From the plot in Figure 6, the R2 value is representing a statistical measure on how close the data are in the fitted regression line. It also indicates the best correlation between two variables. The equation and regression values as shown in Table 3.

From the equation of line and regression value of the sensor 800 nm, 940 nm and 950 nm, the best performance between those three sensors is 940 nm. The NIR sensor of 940 nm wavelength has higher value of regression which is 0.965 compared to 950 nm which is 0.9615. The highest value of regression and it means that there is a good correlation between both variables. This proves that the linear relationship between the output voltage and glucose concentration is significant.

The inconsistency of some output voltage readings may be due to the slight movement of sensor positions while the test tube is being replaced with a different concentration. Other than that, is also caused by stability of placeholder which is not shielded the sensor from ambient light.

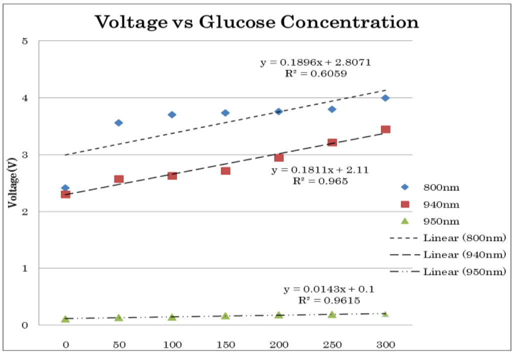



Fig. 6. Relationship between voltages and glucose concentration

## IV. CONCLUSION

As a conclusion, results showed that these two variables have a strong linear relationship; measured voltage increases as glucose concentration increases for all NIR sensors used with 940 nm wavelength shows the best fitted correlation. This proved that the non-invasive technique using NIR sensor is reliable to be used to measure glucose in blood. However, the measurement of the developed device is still not stable due to the factor of surrounding light and may be due to the changing position of the sensors during the test and open for future improvement.

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