Development of a glucose sensor system with real time calibration

M.M Rashid, Nadhirah Mokhtaruddi, Md. Julkar Nayen

Abstract--- This research discussed on developing a glucose sensor with real time calibration. In general cases, the blood sugar level is checked through puncturing the fingertip to get the blood sample on a test strip. Moreover, this method is not convenient for the patients because it requires changing of the strips for taking the blood samples every time and its price is also higher. This may expose the patients to infections while taking the blood samples. A non-invasive method is developed in this work to improve the old method. A near infrared (NIR) sensor is used to detect the scattering and absorption of light through glucose concentration. The simulation and construction of glucose sensor circuit are implemented through testing different solutions of glucose concentration (50-300 mg/dL) using microcontroller and Matlab software. The data of blood tests from 6 patients are compared and analyzed with the constructed glucose sensor. Results show that, the glucose sensor can detect the glucose concentrations (hyperglycemia, normal and hypoglycemia level) through finger and display it on Liquid Crystal Display (LCD). This sensor is able to provide an alert if glucose level reach higher than normal range. So the diabetes disease can be monitored in real time without difficulties of the patients in addition this method is competitive, affordable and convenient for the patients.

Keywords: non-invasive method; near infrared (NIR) sensor ;diabetes disease

1. INTRODUCTION

Diabetes is one of the chronic diseases that grows fast in worldwide with a big number of patients which is 346 million. The number of deaths caused by high blood sugar level or diabetes is approximately to 3.4 million deaths every year. Heart disease, stroke, blindness, kidney failure and many more health problems stems from poor management of diabetes [1]. Usually the patients monitor their blood glucose level by puncturing the fingertip in order to get reading of blood sample on a test strip. However, the old method cannot monitor the glucose measurement continuously and also high cost to take the blood sample by keep on changing the blood strip test.

Nowadays, many methods and techniques can be used to check the blood glucose level. The three main methods for glucose measurement are invasive, non-invasive and minimal invasive. The optical technique under non-invasive method which is near infrared (NIR) is widely used due to high penetration in skin [2]. According to Maruo et al, the fibre optical probe is designed to get the spectra of forearms of individuals of type 1 diabetic [3]. In this project, the non-invasive method is chosen because it is painless, low cost and reliable. The changing in concentration of blood glucose can cause the absorption and scattering of light. Those lights can be detected by using photodiode. When the glucose concentration increases, the scattering properties of skin will decrease [4]. The concentration of glucose depends on the amount of wavelength of light that has been transmitted. Figure 1 shows the relationship between scattering properties of skin and the blood glucose concentration.

The range of wavelength in NIR is 0.8 – 2.5 µm and approximate to 400 – 1400 cm^{-1}. Near infrared light can be used to excite harmonic or overtone vibrations. In NIR, the

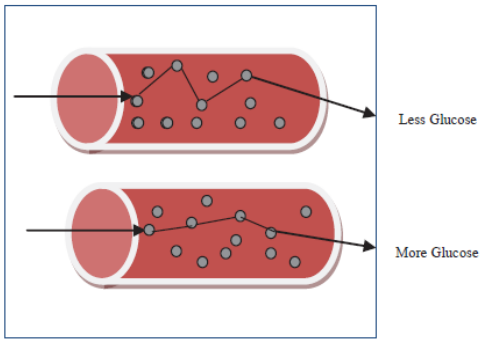

Figure 1: Relationship between scattering properties of skin and the blood glucose concentration

LEDs (light emitting diodes) are used as a light to transmit the light because it has a long lifetime and spectral stability. In this project, a prototype of glucose sensor is developed where it can detect and monitor the level of blood sugar in human body continuously without pricking finger for blood test. Besides, it will also give warnings to patients for high or low level of glucose.

2. SYSTEM DESIGN AND ANALYSIS

The design of this glucose sensor is based on non-invasive method. Thus, near infrared (NIR) LED is chosen to be as a transmitter and photodiode as a receiver. Both components have their own electromagnetic spectrum wavelength range. The NIR LED has a wavelength of 1550 nm meanwhile the silicon photodiode (BPW20RF) has 920 nm of wavelength. The transmitted light from NIR LED will pass through fingertip and the reflected light is received by photodiode. This photodiode will help to convert the light into current.

Then, the amplifier circuit and high pass filter will convert the current into voltage and remove the noises from

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the output photodiode. The microcontroller which is Arduino UNO is used to collect and process the data of voltage to glucose concentration level. The result of glucose concentration is displayed on LCD and computer. Figure 2 shows a simple block diagram of NIR system device

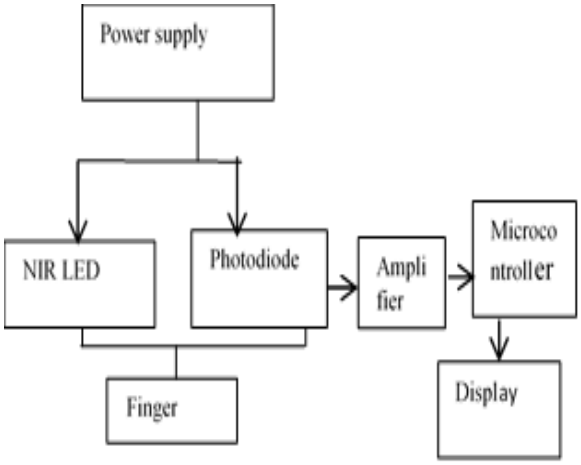

Fig. 2: Block diagram of NIR system

2.2. Simulation and analysis

First, the glucose sensor that has been constructed is tested with different concentration of glucose. The aim of this experiment is to analyze the relationship between the output voltage of photodiode and the glucose concentration. Therefore, six glucose concentrations are prepared which are 50 mg/dL, 100 mg/dL, 150 mg/dL, 200 mg/dL, 250 mg/dL and 300 mg/dL. Once the result has been obtained, a comparison between theoretical and experimental result are analyzed. The calculation between glucose concentration and output voltage as follows:

$$mg/dL = 21.998\ (V)2 - 157.73\ (V) + 335.55 \quad (1)$$

From the result, it shows that when the concentration of glucose is increasing, the output voltage of photodiode is decreasing. There are lot of glucose molecules in high concentration and caused the arrangement of glucose to be packed. Thus, the intensity of light from near infrared LED is less and the light path that will be received by photodiode is shorten. This caused the output voltage of photodiode to be lower. The error between theoretical and experimental for 200 mg/dL glucose concentration has a larger difference compared to others. This is due to the interference of outside light that passed to the cuvette. The result achieved from this experiment is presented in Table 1, Figure 3 and Figure 4 below.

1. RESULTS

Table 1: Comparison error (%) between theoretical and experimental glucose sample

Concentration (mg/dL)	50	100	150	200	250	300
Theoretical (V)	3.590	2.120	1.480	0.998	0.590	0.230
Experimental (V)	3.670	2.170	1.430	0.880	0.620	0.250
Error (%)	2.23	2.36	3.38	11.82	5.09	8.70

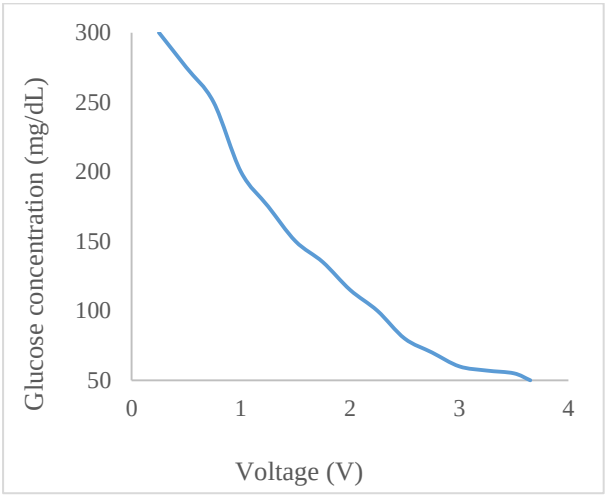

Fig. 3: Graph of theoretical between glucose concentration and output voltage

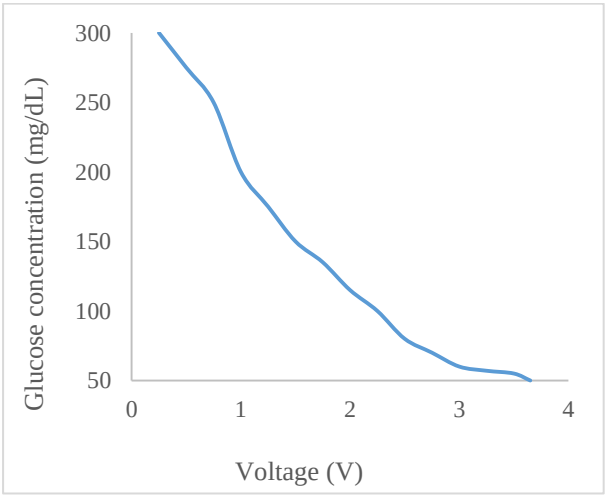

Fig.4: Graph of experimental between glucose concentration and output voltage

In second experiment, the blood glucose test of five persons are tested by using OneTouch Select Simple Glucometer. The results of blood glucose test are then compared with glucose sensor's reading that has been constructed for this project. Refer to table below, the error and difference between readings of glucose concentration from blood test and glucose sensor are slightly difference. The result also shown that the blood test reading is proportional to glucose sensor reading. Figure below shows the comparison graph between blood test and glucose sensor for five persons.

Table 2: Blood test and glucose sensor reading for 5 persons

Person	Blood Sample(mmol/L)	Glucose Sensor(mmol/L)	Error (%)
1	6.0	5.50	8.33
2	4.9	4.40	10.20

3	7.1	7.18	1.13
4	12.3	12.22	0.65
5	14.9	13.55	9.06

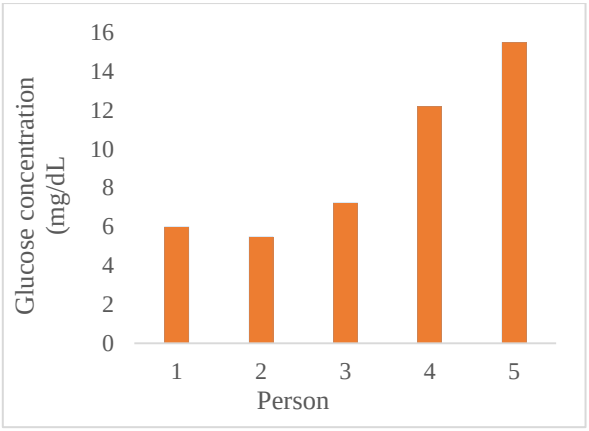

Fig. 5: Comparison graph between blood test glucometer and glucose sensor reading

2. CONCLUSION

As a conclusion, a glucose monitoring system has been developed for this project by using near infrared (NIR) LED and photodiode. The objective of this project which is to analyze the data from glucose sensors which are the NIR LED and photodiode has been achieved. Even though there are some errors in the data analysis, but it still can be overcome by doing the list of recommendations. Firstly, the accuracy of glucose concentration from data analysis can be improved by doing testing in a darker place to get more accurate reading of output voltage from photodiode. Besides, it also can help to avoid other interferences of light that can pass through finger. Another suggestion is using a component that has high wavelength to transmit the light and reach the glucose in blood capillaries such as laser. This can help to give more accurate result of glucose concentration reading. This glucose sensor has its own limitation where it cannot pass over range of 1550 nm of light wavelength. Thus, by having this system, the diabetes disease can be maintained.

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