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Comparative study of 940 nm and 1450 nm near infrared sensor for glucose concentration monitoring

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Abstract

In order to manage their blood glucose level, diabetics have to test their blood glucose level regularly. Unfortunately, the current blood glucose measurement device is uncomfortable, painful, event costly for the diabetics; therefore, a lot of effort is given to develop a noninvasive blood glucose meter. We studied the potential of two near infrared wavelength i.e. 1450 and 940 nm as glucose sensor. Each sensor consists of a light emitting diode (LED) as light source, a photodiode that is sensitive to that wavelength, transimpedance amplifier, and filters. An acrylic box size 5cmx1cmx5cm was used as glucose solution container. The LED and photodiode were located at each side of box width, at 1 cm distance. The container was than filled with various concentrations of glucose solution, and the sensor output voltages were measured. The results show that for glucose concentration 0 to 500 mg/dl, the output voltages of the 1450 nm sensor tend to lower when the glucose concentration is higher, therefore it has the potential to be used as glucose sensor. Different result is obtained from the 940 nm sensor where the output voltages were remained the same when the glucose concentration was varied.

Keywords: *glucose concentration, glucose sensor, glucose monitoring, near infrared*

1. Introduction

Diabetes mellitus (DM), or simply diabetes, is a metabolic disorder of multiple aetiology characterized by chronic hyperglycemia with disturbances of carbohydrate, fat, and protein metabolism resulting from defects in insulin secretion, insulin action, or both [1]. Generally, the injurious effects of hyperglycemia are separated into macrovascular complications (coronary artery disease, peripheral arterial disease, and stroke) and microvascular complications (diabetic nephropathy, neuropathy, and retinopathy) [2]. While diabetic nephropathy is the cause of renal failure, diabetic retinopathy is responsible for blindness. More than 80% of amputation occur after foot ulceration or injury, can result from diabetic neuropathy [3].

According to International Diabetes Federation (IDF) Atlas 2017, 1 in 11 (425 million) adults has diabetes and 12% of global health expenditure (727 billion USD) is spent on diabetes [4]. While the major cost drivers are hospital and outpatient care, a contributing factor is the rise in cost for analogue insulin [5]. In 2016, Indonesia has population of 258 million people and 7% prevalence of diabetes [6], which means around 18 million Indonesian have diabetes. These huge number bring substantial economic loss to people with diabetes and their families, and to health systems and national economies through direct medical costs and loss of work and wages. In order to be able to live well with diabetes, an early diagnosis is needed. Diabetes may be diagnosed by measuring glucose in a blood sample taken while patient is in a fasting state or 2 hours after a 75-g of oral glucose tolerance test (OGTT) [7]. Table 1 shows criteria for diagnoses diabetes and prediabetes [8].

Table 1. Criteria for the Diabetes Mellitus Diagnosis

Plasma glucose test	Normal (mg/dl)	Prediabetes (mg/dl)	Diabetes (mg/dl)
Fasting	100	100-125	126
2 hours post prandial	140	140-199	200

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While diabetes cannot be well cure completely, it can be controlled, and its complication effects can be prevented by maintaining blood glucose level in certain advisable normal range. In order to manage their blood glucose level, diabetics have to measure their blood glucose as often as possible according to certain medical guidance, diet, exercise, and if necessary, consume medicine. The level of glucose in the blood can be measured by applying a drop of blood to a chemically treated, disposable test-strip, which is then inserted into an electronic blood glucose meter. The reaction between the test strip and the blood is detected by the meter and displayed in units of mg/dl or mmol/l [9]. This measurement method is invasive, which is inconvenient, uncomfortable, painful, even creates infection risk to the diabetics or patients. Furthermore, the use of disposable test strip is costly.

Recently, a small and low cost biosensor have been developed as glucose sensor in which liquid specimen is needed [10-11]. Even though this sensor is preferable than the invasive ones, the need for liquid specimen is still inconvenient and special effort is needed to collect the liquid from the body. Noninvasive blood glucose measurement method has many advantages compared to invasive one, such as more convenient and comfortable for diabetics, allow easy and continuous monitoring and more cost effective, therefore a lot of attention is given to develop a noninvasive blood glucose measurement device.

Optical methods are ones that can be used for noninvasive blood glucose measurement. One of popular optical methods is near infrared (NIR) spectroscopy, which uses light in 750-2500 nm wavelength. This concept is based on the transmission NIR light band through a vascular area of the body (finger, ear, tongue, etc.), and the glucose concentration in vivo is calculated from the spectral information obtained at the reception [12]. NIR sensor for blood glucose measurement has been widely explored. Sia used LEDs with 1450 and 2050 nm wavelength and photodiodes as means to measure voltage of solution with 50, 100, 150 and 200 mg/dl glucose concentrations [13]. Transmittance results were observed when using near-infrared light of wavelength 1450nm. As glucose concentration increases, output voltage from the photodiode also increases. However, this result is not in agreement with Beer-Lambert Law which stated that relationship between absorbance and concentration of an absorbing species is linear.

Chua et al. used 8 pairs of LEDs i.e. red, orange, blue, green, white, ultraviolet, 1450 nm, and off-the- shelf IR LED and measured output voltage of glucose concentration from 0 to 720 mg/dl. Their results show that in the range of normal glucose samples, the infrared LED with wavelength 1450 nm exhibited an upward trend but with some dips. The same trend can also be seen with the hyperglycemic glucose samples [14]. Yadav et al. used 940 nm NIR LED to measure different glucose concentrations in vitro and observed diffused reflectance spectra of blood from human forearm. The results are promising and show the potential of using NIR for glucose measurement, however the performance of the proposed method can be improved by reducing the positioning error and by the use of suitable signal processing techniques to remove interferences [15]. Amir et al. have done clinical study to quantify the in vivo performance of the noninvasive blood monitor device [16]. Unfortunately, in spite of almost 20 years of research, a reliable and accurate non-invasive NIR glucose-monitoring device is yet to be developed [17].

As a preliminary research to obtain blood glucose monitoring device, the potential of two NIR wavelength i.e. 1450 and 940 nm as glucose solution sensor were studied. In order to be able to provide similar environment condition during measurement, in vitro testing was conducted in which the sensors are tested in glucose solutions, rather than in vitro testing where the environment conditions were unknown. More detailed description of measurement method is presented in section 2. Results and analysis are provided in section 3. The conclusions are given in section 4.

2. Research Method

Two glucose sensors were designed and used in the experiments. The main difference between the two sensors was the wavelength of the light sources. LEDs are used as the light source. One sensor had 1450 nm LED while the other had 940 nm LED. The 1450 nm wavelength was chosen because it is one of the wavelength where the glucose absorbance is higher, while the 940 nm LED was chosen because it is cheaper than the 1450 nm LED. Glucose has higher absorption in 1450 nm compare to 940 nm wavelength [13, 15], however the 1450 nm LED was far more expensive then the 940 nm LED. A photodiode sensitive to

800-1700 nm wavelength was used to detect the NIR light. The 1450 nm wavelength is in the overtone band of glucose absorption [18] where the glucose absorption is higher compared with 940 nm, therefore the 1450 nm sensor was expected more sensitive than the 940 nm sensor. Transmittance setup was chosen in which the photodiode was placed in opposite direction to the LED. A 5cmx1cmx5cm acrylic box is used as glucose solution container. The schematic of measurement method is shown in Figure 1.

The block diagram of the NIR glucose sensor is shown in Figure 2. Each sensor consists of a LED, a photodiode, an amplifier and a filter. The amplifier used in this design was a transimpedance amplifier (TIA) which converted photodiode current to voltage. A capacitor was added parallel to the TIA feedback resistor as a filter to reduce high frequency noise. Glucose solution with 0, 50, 100, 200, 300, 400, and 500 mg/dl concentrations were made from 5% (50 g/l) glucose solution mixed with water. The environmental conditions, such as room temperature and voltage supply, were kept similar for all measurement. The room temperature was around 22 ºC. A standard laboratory power supply was used to provide 5 V constant supply. The sensor output voltages were measured and observed using a digital oscilloscope.

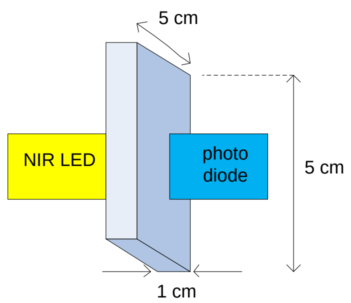

Figure 1. Schematic of measurement method

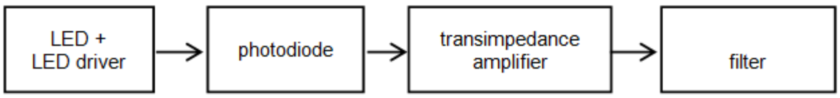

Figure 2. NIR glucose sensor block diagram

3. Results and Analysis

The 1450 nm sensor output voltages for 0, 50, 100, 200, 300, 400, and 500 mg/dl glucose concentrations are shown in Table 2. The average (DC) and peak to peak (PP) voltages are measured using digital oscilloscope. The TIA feedback resistance is 100 MΩ and the capacitance is 1 nF. The 100 MΩ resistance is used to produce large enough sensor output voltage when used in glucose solution because the water absorbance in this wavelength is high. With no solution between LED and photodiode, the DC value of TIA output voltage is 4.61 V with very small (unmeasured) AC voltage. When container filled with water (0 mg/dl glucose solution) was placed between LED and photodiode, the TIA output DC voltage drop to 1.58 V; however, a 50 Hz interference with peak to peak voltage 0.880 V is measured at the TIA output.

The origin of 50 Hz interference is the mains power supply [19], however the disturbance mechanism in these experiments were not obvious. Several effort was made to reduce the 50 Hz interference such as using power bank instead of standar laboratory power supply as well as using multimeter instead of oscilloscope to isolate the sensors from the mains power supply, turning off the room light, and covering the sensor with metallic case, however, despite all of the effort, no interference reduction were observed.

Table 2. The 1450 nm Sensor Output Voltages

Glucose solution (mg/dl)	TIA Output Voltages (V) DC	PP
0	1.58	0.880
50	1.57	0.860
100	1.57	0.860
200	1.57	0.850
300	1.57	0.860
400	1.56	0.870
500	1.58	0.880

The source of large voltage drops of water and glucose solution compared to air is high water absorbance in 1450 nm wavelength [20]. The 1450 nm sensor output voltages in Table 2 show that at the output voltages tend to lower when the glucose concentration is higher. This result is consistent with our previous result [21] and the other team results [13, 14, 22].

The 940 nm sensor output voltages for 0, 50, 100, 200, 300, 400, and 500 mg/dl glucose concentrations are shown in Table 3. In order to keep the TIA in unsaturated condition, the feedback resistance was reduced to 10 MΩ while the capacitance was maintained at 1 nF. This 10 MΩ resistance value is lower than the resistance in 1450 nm sensor because the water absorbance in this wavelength is low, therefore more NIR light is received by the photodiode and caused the current in the photodiode to be high enough to produce TIA output voltage with lower resistance value without saturation. With no solution between LED and photodiode, the TIA output voltage is 4.69 VDC and 80 mVpp 50 Hz interference was observed. When water (0 mg/dl glucose solution) is placed between LED and photodiode, there is no change in TIA output voltage.

Table 3. The 940 nm Sensor Output Voltages

Glucose solution (mg/dl)	TIA Output Voltages (V) DC	PP
0	4.69	0.080
50	4.69	0.080
100	4.69	0.080
200	4.68	0.080
300	4.69	0.080
400	4.68	0.080
500	4.69	0.080

The measurement results show that water absorption at 940 nm is minimum, therefore, same value of sensors output voltage for air and water was obtained. From the data in Table 3., the relation between output voltages and glucose concentration is not conclusive. This result is different from other group result in which the sensor output voltages tend to lower when the glucose concentration is higher [15].

4. Conclusion

As a preliminary research to obtain blood glucose measurement device, the potential of two NIR wavelength i.e. 1450 and 940 nm as glucose solution sensor were studied. In order to be able to provide similar environment condition during measurement, in vitro testing was conducted in which the sensors are tested in glucose solutions, rather than in vitro testing where the environment conditions were largely unknown. The results show that for glucose concentration 0 to 500 mg/dl, the output voltages of the 1450 nm sensor tend to lower when the glucose concentration is higher, therefore it has the potential to be used as glucose sensor. Different result is obtained from the 940 nm sensor where the output voltages were remained the same when the glucose concentration was varied.

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