Noise reduction in near infrared-based glucose concentration measurement sensor

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Abstract. This paper describes the method of measuring glucose concentrations in solution using near infrared light (NIR) and photodiode sensor. A sensitive and accurate non invasive blood glucose level sensor is our main concern in designing this device. The sensor consists of a transimpedance amplifier, a notch filter and a low pass filter to reduce high frequency noise and 50 Hertz noise from the power line induction. Light Emitting Diode (LED) with 1450 nm wavelength is used as a light source and a photodiode is used as a sensor to sense this wavelength. The NIR light received by the photodiode after passing glucose solution is converted to voltage signal and filtered to determine the output voltage. The measurement results show that the filters reduced the AC voltage or noise signal under 100 mV and the DC voltage tended to decrease as glucose concentration increase until 700 mg/dL.

1. Introduction
Diabetes Melitus or simply diabetes, is a chronic disease that occurs when the pancreas is no longer able to make insulin, or when the body cannot make good use of the insulin it produces. World Health Organization, Global Report on Diabetes reported that over time diabetes can damage the heart, blood vessels, eyes, kidneys and nerves and increase the risk of heart disease and stroke [1]. According to IDF Atlas 2015, 415 million adults live with diabetes and there were 5 million deaths caused by diabetes. In Indonesia approximately 10 million adults (20 to 79 years old) live with diabetes and as many as 6 million adults live with undiagnosed diabetes, making Indonesia’s diabetes population the seventh largest in the world [2].

The causes of diabetes in humans are not yet fully understood, but the widely accepted hypothesis is that it may be genetic and may be caused by high sugar intake as part of daily meal serving. Diabetics are insisted to regulate their blood glucose levels through proper diet and by injecting insulin. Effective treatment for diabetics is to measure blood glucose levels periodically. The current method available is invasive one that needs blood samples to measure blood glucose level. This is the main disadvantage of the invasive method because it requires pricking the finger that gives pain and discomfort due to frequent finger pricks and increase risk of infection. Figure 1. shows the invasive method for measuring blood glucose level.

Developing non invasive technique would be much more useful and user friendly from the user point of view. The main advantage of non-invasive method is the relief from pain and discomfort due to frequent finger pricks. This method is proper for continues monitoring of blood glucose level and reduces the healthcare cost [3].
One of popular optical method for non invasive blood glucose is near infrared (NIR) spectroscopy since NIR light is found to penetrate a great depth into biological tissue. This concept is based on the transmission of 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 [4].

![Figure 1. Invasive blood glucose measurement.](image)

For the last two decades, NIR sensor for blood glucose measurement has been widely explored. Menon et al. proposed a method that makes use of the variation in the intensity of the signal that received from the NIR sensor to detect whether a patient is diabetic or not [3]. Chua et al. used 8 pairs of LEDs with different colors and tested for sensitivity to different glucose concentrations [5]. Narkhede et al. used NIR LED of 940 nm wavelength through fingertip and the reflected signals were detected by phototransistor placed beside the LED [6]. Bobade et al. proposed a technique used a near infrared sensor for transmission and reception of rays from forearm. By analyzing intensity variation in received signal by using photo detector at another side of forearm, level of blood glucose can be predicted [7].

In our preliminary research, we designed and developed a non invasive sensor using a pair of NIR LED at 1450 nm because the wavelength is in the overtone band of glucose absorption and a photodiode that sensitive to 800 to 1700 nm wavelength to determine glucose concentration in glucose solution. The results showed that higher glucose concentration yield lower sensor output voltage. This result is consistent with Beer Lamberts law that attenuation of light is proportional to the level of glucose solution, thickness of the sample and molar extinction coefficient. Equation (1) shows the attenuation $A$ according to Beer Lamberts law [8].

$$A = \log \left( \frac{I_o}{I} \right) = \varepsilon Cl$$  

where $I_o =$ transmitted light intensity, $I =$ incident light intensity, $\varepsilon =$ extinction coefficient, $C =$ concentration of glucose solution, $l =$ length of light path through solution being observed.

The linear trend line of sensor output voltage as function of different glucose concentration showed good fit with those recorded data that measured in our preliminary research. The value of correlation coefficient is -0.99 which indicated strong relationship between the sensor output voltages and glucose concentrations [8]. In our second year of research, a sensitive and accurate non invasive blood glucose level sensor is our main concern in designing this device so we analyzed and reduced the noise signals that occurred.
2. Research method
2.1. Block Diagram of the System
In this proposed design we complete the system with a transimpedance amplifier and noise reduction circuits to get an accurate small signal that the photodiode senses for a high accuracy reading of glucose concentration solution. Figure 2. shows the block diagram of the system.

An NIR LED of 1450 nm wavelength from ThorLabs is the light source as the input section of the system. An infrared photodiode from the same factory is used as the detector of the IR light that senses the 800 to 1700 nm light wavelength. The amount of IR light passing through glucose solution is received by an infrared photodiode. This attenuated signal is amplified and filtered.

![System block diagram.](image)

2.2 The Amplifier and Noise Reduction Circuits
The IR sensor photodiode is connected to a transimpedance amplifier to convert the current from photodiode sensor to voltage as seen in Figure 3. Due to its low output impedance, this circuit allows viewing the output signal with an oscilloscope to analyze the noises that occurs.

![Transimpedance amplifier.](image)

The circuit output voltage is:

\[ V_{01} = I_{pd} \cdot R_F \]  \( (2) \)

\( I_{pd} \) is the reverse current from the photodiode sensor. The TLC274 op amp is used for this transimpedance amplifier due to its low input offset voltage and low input bias current, the output offset voltage can be neglected.

The output signal from the transimpedance amplifier is filtered by a 50 Hz notch filter and a 50 Hz low pass filter because it is the most disturbing frequency noise from the power line besides the high frequency noise. Capacitor \( C_F \) in feedback path in transimpedance amplifier reduces the high frequency noise. Figure 4. shows the 50 Hz second order notch filter and Figure 5. is the frequency response of the filter.
The notch frequency of the filter is:

\[ f_n = \frac{1}{2\pi R_1 C_1} \]  

(3)

We measured the output voltage by giving 1 volt peak to peak sine wave from 10 Hz to 400 Hz to the input of the notch filter. As it is shown in Figure 5., the 50 Hz output voltage gets the highest attenuation. The 50 Hz low pass filter is cascaded to the notch filter to give more attenuation to the 50 Hz noise and it is shown in Figure 6. and Figure 7. is the frequency response of the second order low pass filter.

The cut off frequency of the low pass filter is:

\[ f_{ct} = \frac{1}{2\pi R_3 C_3} \]  

(4)

We measured the output voltage of the low pass filter by giving 1 volt peak to peak sine wave from 10 Hz to 100 Hz to the input of the low pass filter.

3. Measurement method

In this experiment we put some glucose solution concentrations in an acrylic box with 1 cm thickness, 5 cm height and 5 cm width. Figure 8 shows the experiment diagram.
The glucose solutions were made by mixing 5000 mg/dL infuse glucose solution with water to get 50, 100, 200, 300, 400, 500, 600, 700, 800, 900, and 1000 mg/dL glucose concentrations. The environmental conditions, such as room temperature and supply voltage were maintained constant in a laboratory. The infrared light was emitted through the glucose solution and the incident light was received by the photodiode on the other side of the acrylic box. The infrared light was then converted to voltage by a transimpedance amplifier and filtered by the notch filter and low pass filter to reduce the 50 Hz and high frequency noises. We measured the photodiode output voltage and the filter output voltage with a Metrix digital voltmeter and a digital oscilloscope to see the noises.

4. Result and discussions
The LED was driven by a DC voltage so the photodiode received a DC voltage too. The oscilloscope showed there were a 50 Hz sine wave noise voltage and high frequency noise besides the DC input voltage from the LED. The transimpedance amplifier output voltage and the filter output voltage for water and various glucose concentrations measurement result is shown in Table 1. The DC and rms AC output voltage signal from the transimpedance amplifier is shown in Figure 9.

| Glucose conc (mg/dl) | Transimp Vout (VDC) | Vout (VRms) | Filter Vout (VDC) | Vout (VRms) |
|----------------------|---------------------|-------------|------------------|-------------|
| Water                | 0.69                | 0.75        | 0.71             | 0.09        |
| 50                   | 0.79                | 0.74        | 0.72             | 0.01        |
| 100                  | 0.72                | 0.79        | 0.75             | 0.03        |
| 200                  | 0.53                | 0.68        | 0.72             | 0.01        |
| 300                  | 0.62                | 0.67        | 0.70             | 0.01        |
| 400                  | 0.69                | 0.74        | 0.70             | 0.01        |
| 500                  | 0.75                | 0.70        | 0.69             | 0.01        |
| 600                  | 0.56                | 0.70        | 0.56             | 0.01        |
| 700                  | 0.71                | 0.77        | 0.56             | 0.01        |
| 800                  | 0.67                | 0.72        | 0.73             | 0.01        |
| 900                  | 0.65                | 0.68        | 0.70             | 0.01        |
| 1000                 | 0.66                | 0.71        | 0.69             | 0.01        |

As seen in Figure 9, almost all the rms AC voltage is higher than the DC voltage, it means that the noise voltages are higher than the information signal voltage.
Figure 9. The transimpedance amplifier output voltage.

Figure 10. The filter output voltage.

The blue line or the DC signal voltages do not reduce linierly as the glucose concentrations increase. The DC voltages were randomly changed as the glucose concentrations increase. According to Beer Lamberts law, as the glucose concentration increases the lower the sensor output voltage. The output voltage from the filter in Figure10. can be seen that the rms AC voltages are reduced lower than 100 mV after it passed the filters. The DC voltages tend to decrease as the glucose concentrations increase until 700 mg/dL and it is in the range of human blood glucose. The DC voltages increase again after the glucose concentration is more than 700 mg/dL.

5. Conclusion
In this research we complete the system with a transimpedance amplifier, a notch filter and a low pass filter to get a high accuracy reading of blood glucose level. The filter circuits in this system reduced noise significantly and the DC voltage signals from the photodiode sensor tend to decrease as the glucose concentrations increase. This system is still not sensitive enough to distinguish one glucose concentration to the other concentration because the voltage difference is not proportional between concentrations so we still have to improve the system.

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