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# Initial Quantitative Comparison of 940nm and 950nm Infrared Sensor Performance for Measuring Glucose Non-invasively

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***Abstract*—This project uses a non-invasive method for measuring the blood glucose concentration levels. By implementing two infrared light with different wavelength; 940nm and 950nm based on the use of light emitting diodes and measure transmittance through solution of distilled water and d-glucose of concentration from 0mg/dL to 200mg/dL by using a 1000nm photodiode. It is observed that the output voltage from the photodiode increased proportionally to the increased of concentration levels. The relation observed was linear. Nine subjects with the same age but different body weight have been used to observe the glucose level during fasting and non-fasting. During fasting the voltage is about 0.13096V to 0.236V and during non-fasting the voltage range is about 0.12V to 0.256V. This method of measuring blood glucose level may become a preferably choice for diabetics because of the non-invasive and may extend to the general public. For having a large majority people able to monitor their blood glucose levels, it may prevent hypoglycemia, hyperglycemia and perhaps the onset of diabetes.**

***Keyword – Infrared, photodiode, light emitting diode, transmittance, glucose***

## I. INTRODUCTION

Diabetes mellitus has become the serious medical condition in which it may cause blindness, obesity, heart disease, renal failure and the stroke [1-3]. These killer diseases affects on the ability of human bodies in producing and utilization of the insulin. It is a hormone which is essential in processing the blood glucose. The World Health Organization estimated there will be 177 million who suffered diabetes in 2000. By the year 2025, the value will increase up to 300 million minimally [4-6]. Glucose concentration is a measurement of the quantity of glucose molecules that present in the liquid solution. Glucose in the blood or urine is an important indicator of healthy or sick. Glucose measurement usually expressed as millimoles per liter (mmol/l). The glucose concentration in blood often to rises after meal. Blood glucose usually is at its lowest it the early morning when someone gets up and does not take breakfast yet.

Blood glucose test to determine the sugar level is usually implemented by placing drop of blood at the test strip which contains special chemical that will then interact with the glucose in the blood. To determine the glucose concentration level, test trip then will be placed into a specially configured meter which will provide a reading showing the glucose concentration level in the blood. This type of test required a sample of blood to be used [7]. The problem with this method is cause pain to the patient for taking blood sample. It is also hard to interpret the reading especially for non-clinical background.

Referred to paper written by Dino Sia [9]; used two different wavelength of near infrared which are 1450nm and 2050nm as the sensing part. As the results, there were no respond of output reading during through finger test and the output voltage remained constant. Another test that had been done was by using different concentration of glucose. From the paper, it shown that output response to the glucose concentrations by using 1450nm were in between 1616mV to 1720mV. By implemented 2050nm infrared the output reading remained constant even though tested by different concentrations of glucose. From this research shows that infrared with 1450nm gave better response compared to 2050nm.

The objectives of this project are to compare the response of two different wavelength of infrared transmitter and to design and develop a low cost non-invasive blood glucose sensor. For this project, infrared had been used but with smaller wavelength as what can be seen from Sia, which smaller wavelength gave better response. As the design goes towards low cost, infrared sensor were chosen based on responsivity versus infrared wavelength graph which shown the highest responsivity around 900 to 1000nm wavelength.

Based on the wavelength as guidance, according to availability in the market infrared with wavelength 940nm and 950nm had been chose. To determine the blood glucose level, the output voltage had been measured in two test; different percentage of glucose concentration and trough finger. To make sure that the output voltage from photodiode not too small as what had been obtained by Sia, signal conditioning circuit had been implemented to get suitable output reading.

## II. METHODOLOGY

Infrared transducer consists of six stages which include of buffering, amplifiers, filtering and linearization. The construction of the circuit is done by using two methods. First, design through software using the Proteus 7 Professional and the second method is hardware design. The Proteus 7 Professional is a friendly user's software where it can be used to construct and simulate the circuit by ensuring the circuit is running properly [8]. The second stage which is hardware, the circuit will be constructed similarly as the one from simulation into the breadboard. Then data output from the hardware will take and compare with the simulation. After the circuit had been tested, the result should be approximately as the simulation. The input voltage of the circuit will be replaced with the photodiode 1000nm. In the simulation there in no current to voltage stage but for the hardware it will be added. The reason is that, the value output from photodiode is in negative. Current to voltage stage can act as an extra buffer to convert back polarity from negative to positive to make it easier to compare with the data value from software. These circuits are used for the receiver part. Meanwhile, the transmitter circuit will be constructed by using two different wavelengths which 940nm and 950nm. The seven stages of the signal conditioning are shown in Fig. 1. Linearization consists of two stages.

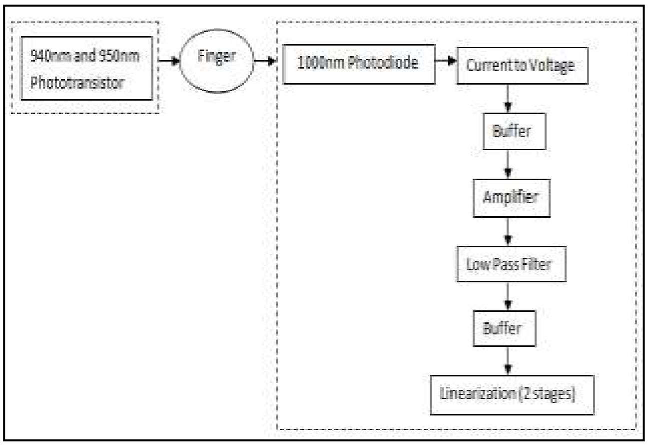

Fig. 1: Signal Conditioning Stage

### A. *PROTEUS PROFESSIONAL SOFTWARE SIMULATION*

#### *i. Buffer*

Buffer as in Fig. 2 provides electric impedance where the function is to provide distortion-free for the signal processing. Three buffer stages been used in the signal conditioning circuits. The first one is after the current to voltage converter op-amp, the second one is after low pass filter stage and the third one is used with the linearization stage. The gain for this buffer is set as unity and the effect of this stage is to change the polarity to the opposite.

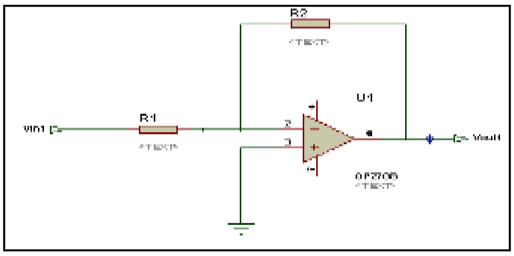

Fig. 2: Buffer Stage

#### *ii. Amplifier*

Amplifier as in Fig. 3 used to step up or step down the voltage through the op-amp [9]. This will affect the amplitude of the signal and beside that; the purpose is to step up the small value output into suitable high value outputs. The input of this stage is from the previous stage which is buffer stage where the voltage that been given from the photodiode is very small and needs to be amplified with gain 10, as a formula amplifier is:

$$Vo2 = -Vin2\left(\frac{R3}{R4}\right) \tag{1}$$

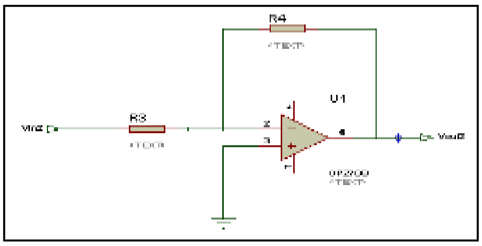

Fig. 3: Amplifier Stage

#### *iii. Filtering*

Filtering is a stage that is designed to pass a desired signal and frequencies, reject and attenuate the other unwanted signal such as noise [9]. The circuit is the combination of resistor and capacitor in parallel. Low pass filter is used to eliminate the frequency higher than 5Hz. The frequency below 5Hz is used to define glucose in the blood.

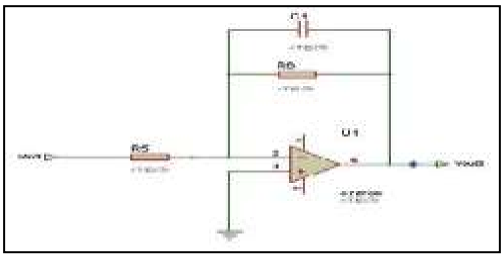

Fig. 4: Low Pass Filter Stage

Figure 4 is the construction of active low pass filter with unity gain, Av and desired low frequency is controlled by C1 and R6. Output gain for this filter is defined as:

$$Av = -(\frac{R6}{R5}) \qquad (2)$$

The active low pass filter will let through only low frequency with a certain bandwidth and there be a cut off frequency. The cut off frequency is calculated from the formula:

$$f = \frac{1}{(2\pi)(R6)(C1)} \qquad (3)$$

*iv. Summing*

Purpose of summing amplifier is to linearize output voltage to the desired value voltage. Before interfacing the voltage to display in LCD display, the data in analog form needs to be linearize to the range of 0V to 5V. The Arduino receives an analog signal in pin A1 and convert it to digital form base on the programming then it will be displayed on LCD display. The circuit is designed to facilitate a signal to be converted to digital for

$$Vout = m(Vin) + Vo \qquad (4)$$

By referring data from simulation, the data will be used to get two equations to calculate the slope gain,m and offset voltage,Vo. The result will be used to adjust the output voltage from the filter stage to get an output voltage in the range of 0V-5V. Below is the formula for summing equation where the offset voltage will be summed with the output of the filter.

$$(\frac{Vin6}{R10}) + (\frac{Vo}{R12}) = -(\frac{Vout6}{R11}) \qquad (5)$$

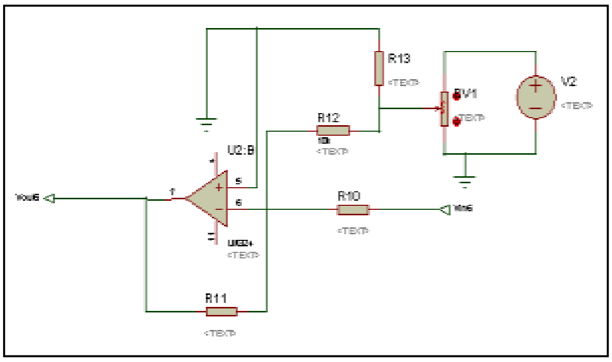


Fig. 5: Summing (Linearization)

*B. HARDWARE DEVELOPMENT*

*i. Infrared Transmitter and Photodiode*

The primary objective is to analyze the detection of the infrared through glucose concentration and the human sample. The infrared wavelengths used are 940nm and 950nm. The photodiode that been decides is 1000nm which is most suitable for both IR LED 940nm and 950nm. The method that will be used is by emitting an infrared wavelength to pass through the finger. Then, the wavelength that passes through will be received by photodiode which act as a photo sensor. The value of the voltage increases as the glucose concentration value increase.

*ii. Circuit Construction ( Breadboard)*

The circuit has been constructed based from the simulation on the Proteus 7 Professional. Type of Op-Amp that been used is OP27G where this Op-Amp withstand high voltage supply up to maximum of 22V. In the hardware design, the voltage supply that been used are +18Vcc and -18Vcc where it's been connected to pin 7 and 4 of the OP27G respectively. The Op-Amp had been arranged in series order for all stages. The connection to the +Vcc, -Vcc, ground, offset, input and output had to be carefully done to ensure there is no mistake that will make the Op-Amp damaged. Troubleshoot will be done for each stage that been added to the circuit to ensure the circuit will run properly as the simulation design. The circuit are being implemented on breadboard and each input and output for each stage will be measure by using multimetre. The output for each stage is being recorded and compare to the simulation result. To achieve the desired results as been design in software, a lot of modification and component testing have been done. One of it, is added current to voltage converter where it is also act as an buffer because the value that been obtained by photodiode are in negative polarity. So, it will change the polarity to positive to make it easier to compare with the data from each stage starting with V1 till Final Output.

*C. PURE GLUCOSE*

Fig. 6: Pure Glucose

The experiment used a pure glucose (D-(+)-Glucose Solution (45%)) to examine whether the voltage changes if the level of the glucose concentration changes. The different concentration of the glucose has various absorption of the spectroscope that affecting the voltage reading. The glucose with high concentration has high absorption, making the light intensity largely diverge into a wide area in glucose solution. The photodiode is sensing this diverging light and the result is a voltage boost up over maximum voltage. The voltage decreases as distilled water mixed into glucose to dilute its concentration. The distilled water contains hydrogen and oxygen ($H_2O$) where it stretches the glucose molecules to loose and it's been reduced the concentration then affecting the absorption of the light intensity [10].

*D. PARTICIPANTS*

Participants (N = 9, males = 6, females = 3) were students from Universiti Teknologi MARA, Malaysia. Participants age, weight and height are being measure and recorded before experimental were done. Participants were paid for their participation. All participants were free of any medication and were asked to fasting from eating, drinking and smoking for 8 hours before their glucose reading are taken in the next morning.

## III. RESULT

| Concentration | | Vin | V1 | | V2 | |
|---|---|---|---|---|---|---|
| % | ms/dL | | Simulation | Hardware | Simulation | Hardware |
| 100 | 200 | 1.68 | -1.67558 | -1.6878 | 16.7759 | 16.766 |
| 90 | 180 | 1.664 | -1.66198 | -1.6741 | 16.6399 | 16.632 |
| 80 | 160 | 1.6528 | -1.64838 | -1.6606 | 16.504 | 16.449 |
| 70 | 140 | 1.64 | -1.63558 | -1.6478 | 16.376 | 16.37 |
| 60 | 120 | 1.628 | -1.62358 | -1.6354 | 16.256 | 16.246 |
| 50 | 100 | 1.616 | -1.61158 | -1.6235 | 16.136 | 16.132 |
| 40 | 80 | 1.616 | -1.61158 | -1.6241 | 16.136 | 16.135 |
| 30 | 60 | 1.616 | -1.61158 | -1.6242 | 16.136 | 16.137 |
| 20 | 40 | 1.616 | -1.61158 | -1.6238 | 16.136 | 16.131 |
| 10 | 20 | 1.616 | -1.61158 | -1.6234 | 16.136 | 16.132 |
| 0 | 0 | 0.6 | -0.5956 | -0.6029 | 5.9774 | 5.978 |

TABLE I. STAGE 1 AND 2

TABLE II. STAGE 3 AND 4

| Concentration | | Vin | V3 | | V4 | |
|---|---|---|---|---|---|---|
| % | ms/dL | | Simulation | Hardware | Simulation | Hardware |
| 100 | 200 | 1.68 | -16.756 | -16.828 | 16.7601 | 16.777 |
| 90 | 180 | 1.664 | -16.62 | -16.692 | 16.6241 | 16.662 |
| 80 | 160 | 1.6528 | -16.4841 | -16.56 | 16.4881 | 16.529 |
| 70 | 140 | 1.64 | -16.3561 | -16.429 | 16.3601 | 16.398 |
| 60 | 120 | 1.628 | -16.2361 | -16.3 | 16.2402 | 16.273 |
| 50 | 100 | 1.616 | -16.1161 | -16.186 | 16.1202 | 16.158 |
| 40 | 80 | 1.616 | -16.1161 | -16.192 | 16.1202 | 16.163 |
| 30 | 60 | 1.616 | -16.1161 | -16.196 | 16.1202 | 16.165 |
| 20 | 40 | 1.616 | -16.1161 | -16.189 | 16.1202 | 16.157 |
| 10 | 20 | 1.616 | -16.1161 | -16.188 | 16.1202 | 16.162 |
| 0 | 0 | 0.6 | -5.9577 | -6.0202 | 5.96195 | 6.008 |

TABLE III. STAGE 5 AND FINAL

| Concentration | | Vin | V5 | | Final Output | |
|---|---|---|---|---|---|---|
| % | ms/dL | | Simulation | Hardware | Simulation | Hardware |
| 100 | 200 | 1.68 | -7.7563 | -7.6444 | 4.9971 | 4.8358 |
| 90 | 180 | 1.664 | -7.6933 | -7.5815 | 4.9342 | 4.7743 |
| 80 | 160 | 1.6528 | -7.6304 | -7.5202 | 4.8712 | 4.7058 |
| 70 | 140 | 1.64 | -7.5711 | -7.4615 | 4.812 | 4.6412 |
| 60 | 120 | 1.628 | -7.5156 | -7.4114 | 4.7564 | 4.5766 |
| 50 | 100 | 1.616 | -7.46 | -7.3521 | 4.7009 | 4.5243 |
| 40 | 80 | 1.616 | -7.46 | -7.359 | 4.7009 | 4.5273 |
| 30 | 60 | 1.616 | -7.46 | -7.3567 | 4.7009 | 4.5278 |
| 20 | 40 | 1.616 | -7.46 | -7.3518 | 4.7009 | 4.5214 |
| 10 | 20 | 1.616 | -7.46 | -7.3542 | 4.7009 | 4.5237 |
| 0 | 0 | 0.6 | -2.75721 | -2.7286 | 0.0018 | 0.2071 |

*i. Simulation and Hardware ( Before use of IR LED)*

Table I, II and III show the value output voltage for each stage start from buffer until linearization. The data that been record are from both simulation and hardware construction before applying the IR Led. From Table I, the value of Vin can be seen. Vin given to the circuit are starting form 1.68V till 0.6V.

TABLE IV. FINAL OUTPUT VOLTAGE AND DISCREPANCY

| Percentage of Glucose Concentration | Final Output Voltage | | Discrepancy |
|---|---|---|---|
| | Simulation | Hardware | |
| 100 | 4.9971 | 4.8358 | 3.23% |
| 90 | 4.9342 | 4.7743 | 3.24% |
| 80 | 4.8712 | 4.7058 | 3.40% |
| 70 | 4.812 | 4.6412 | 3.55% |
| 60 | 4.7564 | 4.5766 | 3.78% |
| 50 | 4.7009 | 4.5243 | 3.76% |
| 40 | 4.7009 | 4.5273 | 3.69% |
| 30 | 4.7009 | 4.5278 | 3.68% |
| 20 | 4.7009 | 4.5214 | 3.82% |
| 10 | 4.7009 | 4.5237 | 3.77% |

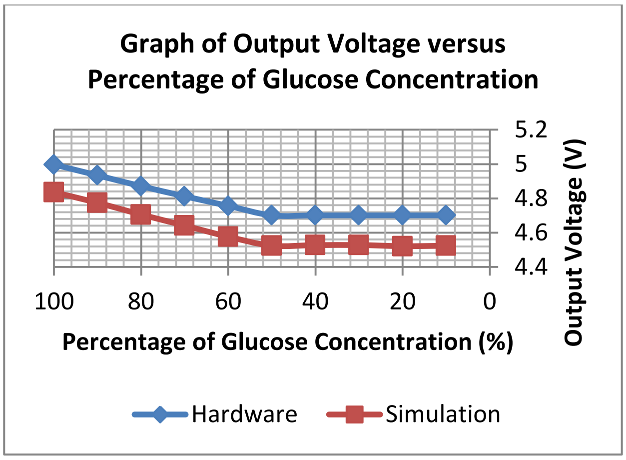


Fig. 7: Graph Simulation versus Hardware (Output)

Based from Table IV and Fig. 7 the data obtain from both simulation and hardware are not that far differ from each other. The calculated discrepancy is very small which below 4%. The last one which is differs from others data can be easily ignored because of the small voltage given to it which 0.6V.

*ii. Glucose Reading*

Fig. 8: Glucose Experimental

From Fig. 8, glucose concentration experimental using two different IR LED 940nm and 950nm had been done to get the glucose reading.

TABLE V. GLUCOSE READING FOR 940nm AND 950nm

| % | Infrared Wavelength | | | | | |
|---|---|---|---|---|---|---|
| | 940nm V1 | 950nm V1 | 940nm V2 | 950nm V2 | 940nm V3 | 950nm V3 |
| 100 | -0.4899 | -0.4672 | 10.0218 | 9.1784 | -10.0589 | -9.2243 |
| 90 | -0.4816 | -0.445 | 9.8625 | 9.1065 | -9.8909 | -9.167 |
| 80 | 0.474 | -0.45 | 9.7056 | 9.159 | -9.7565 | -9.141 |
| 70 | -0.4529 | -0.442 | 9.269 | 8.9836 | -9.295 | -8.9973 |
| 60 | -0.4558 | -0.4391 | 9.3234 | 8.9627 | -9.333 | -8.9912 |
| 50 | -0.458 | -0.4377 | 9.376 | 8.9624 | -9.4026 | -8.981 |
| 40 | -0.4542 | -0.4338 | 9.2965 | 8.9565 | -9.3196 | -8.9529 |
| 30 | -0.4608 | -0.4326 | 9.4501 | 8.8818 | -9.238 | -8.903 |
| 20 | -0.4603 | -0.43502 | 9.4462 | 8.8354 | -9.478 | -8.876 |
| 10 | -0.4604 | -0.4309 | 9.4267 | 8.8313 | -9.4536 | -8.865 |
| 0 | -0.4436 | -0.42272 | 9.0855 | 8.636 | -9.1398 | -8.709 |

TABLE VI. GLUCOSE READING FOR 940nm AND 950nm

| % | Infrared Wavelength | | | | | |
|---|---|---|---|---|---|---|
| | 940nm V4 | 950nm V4 | 940nm V5 | 950nm V5 | 940nm Final | 950nm Final |
| 100 | 10.437 | 9.201 | -5.4981 | -5.541 | 5.4201 | 5.4633 |
| 90 | 9.8714 | 9.129 | -5.4403 | -5.5394 | 5.3396 | 5.2812 |
| 80 | 9.606 | 9.118 | -5.1743 | -5.38 | 5.2489 | 5.2225 |
| 70 | 9.2882 | 8.96 | -5.274 | -5.287 | 5.2045 | 5.2138 |
| 60 | 9.315 | 8.972 | -5.345 | -5.2847 | 5.276 | 5.2064 |
| 50 | 9.3419 | 8.963 | -5.2667 | -5.254 | 5.1891 | 5.182 |
| 40 | 9.2988 | 8.9585 | -5.2412 | -5.165 | 5.1625 | 5.147 |
| 30 | 9.468 | 8.8956 | -5.117 | -5.126 | 5.151 | 5.128 |
| 20 | 9.4548 | 8.869 | -5.2177 | -5.1056 | 5.1345 | 5.087 |
| 10 | 9.4547 | 8.8438 | -5.1463 | -5.0836 | 5.0771 | 5.053 |
| 0 | 9.0817 | 8.7079 | -5.1125 | -5.0167 | 5.0327 | 5.016 |

From Table VI, the output voltage for 940nm and 950nm are nearly linear with the glucose percentage concentration. The lower glucose concentration percentage, the lower it will be for the final output voltage

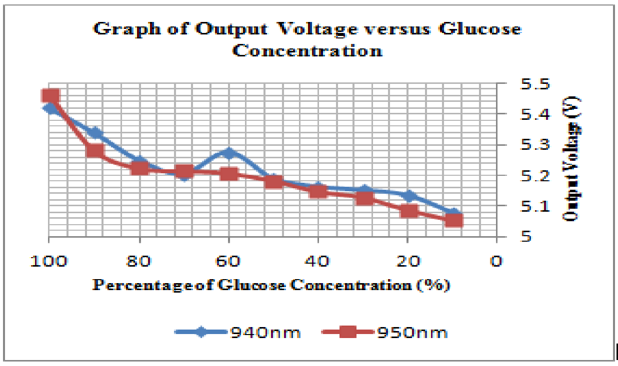


Fig. 9: Graph Output Voltage of 940nm and 950nm versus Glucose Concentration.

Figure 9 shows, the different voltage output reading from two IR wavelengths which 940nm and 950nm. From the graph, the 950nm looks more consistent compare to the 940nm. 950nm also has a larger range scale for voltage which from 5.016V to 5.4633V compare to the 940nm voltage range scale which from 5.0327V to 5.4201V. The percentage increase between 940nm and 950nm is 5.99%.

### iii. *Human Sample Experimental*

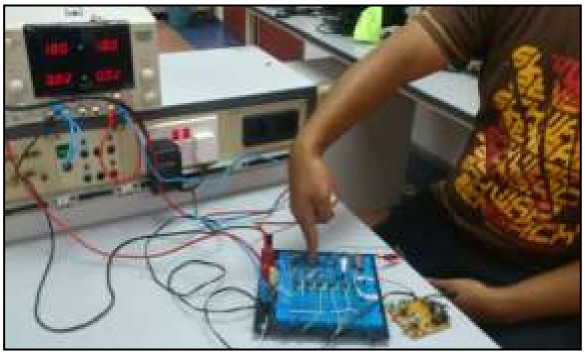

Fig. 10: Human Sample Experimental

Figure 10 shows one of the human samples while taking his glucose reading. The finger is placed between phototransistor and photodiode. The output reading is measured by using multimeter.

TABLE VII. HUMAN SAMPLE READING

| No. | Age | Weight (kg) | Height (cm) | Last Have Meal | Fasting (V) | Non-Fasting (V) | Percentage Increase (%) |
|---|---|---|---|---|---|---|---|
| 1 | 24 | 96 | 171 | 22:00 | 0.13096 | 0.171 | 23.42 |
| 2 | 24 | 91 | 175 | 22:00 | 0.134 | 0.159 | 15.72 |
| 3 | 24 | 55 | 160 | 22:00 | 0.2014 | 0.3056 | 34.1 |
| 4 | 24 | 73 | 174 | 18:00 | 0.1004 | 0.13 | 22.77 |
| 5 | 24 | 67.6 | 173 | 22:00 | 0.10271 | 0.1202 | 14.55 |
| 6 | 24 | 64.5 | 170 | 22:30 | 0.182 | 0.194 | 6.19 |
| 7 | 24 | 56 | 163 | 02:00 | 0.146 | 0.208 | 29.81 |
| 8 | 24 | 57 | 158 | 02:00 | 0.1335 | 0.1815 | 26.45 |
| 9 | 24 | 63 | 169 | 22:00 | 0.236 | 0.256 | 7.81 |

For the human sample reading, only 950nm had been used. This is because of 950nm have larger scale and gave more consistent voltage output reading compared to the 940nm. The comparison voltage measure fasting and non-fasting are recorded in Table VII. The sample that had been taken is random from both male and female. The human sample have been asked to fast for 8 hours before coming to the lab the next day for taking fasting measurements. After lunch, another reading of glucose was taken for recorded which is for non-fasting.

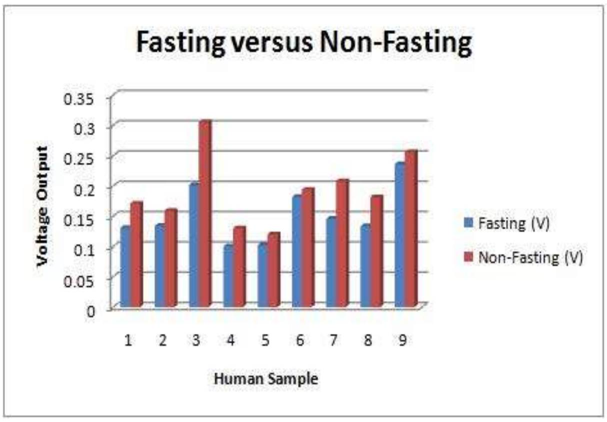

Fig. 11: Fasting versus Non-Fasting

Figure 11 show that non-fasting has a higher voltage output compare to the fasting output value voltage. These indicate the existence of different value voltage for before and after taking meal. From paper Glucose test - blood, NIH – National Institutes of Health. The normal blood glucose level (tested while fasting) for non-diabetics, should be between 70 and 100 milligrams per deciliter (mg/dL). Blood sugar levels for those without diabetes and who are not fasting should be below 125 mg/dL [11]. Which mean a person who is fasting have a lower glucose level than the non-fasting. From the data it proves that the system can give a good response to the difference of blood glucose level.

## IV. CONCLUSION

From the experiment with difference glucose concentration, the final output voltage nearly linear with higher glucose concentration gave higher output voltage. By comparing the output response of infrared 940nm and 950nm during the experimental, both of them gave similar pattern of output response. Both 940nm and 950nm showed that the output voltages are nearly linear with the increment of glucose concentration. From the experiment the human samples also gave the similar output pattern by using the existence of human finger in between of the infrared and photodiode. The output response shows that the sugar taken in human also gave response tally to the glucose concentration experiment. During fasting which considered as the glucose level are low and the output voltage was low while during non-fasting where there were glucose taken and considered that the glucose level were high, the output voltage also high. It shows that those responses are tally and acceptable.

## V. FUTURE DEVELOPMENT

Due to time constraints, further improvement can be made to increase accuracy, repeatability in data collecting, efficiency in signal processing and precision of the data reading using this device which could include data comparison with clinical glucose meter. Other than that, the experiment will need more data sampling for statistical analysis but for this time the human sample will be controlled by their food taken. This is to ensure the data collecting for glucose measuring is more precise for each measurement taken from the human sample.

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