Design and Fabrication of a Non-Invasive Blood Glucometer Using Paired Photo-Emitter and Detector Near-Infrared LEDs

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Abstract: Diabetes mellitus more commonly known as diabetes has been an on-going problem around the world for many years now and the number of diabetics is expected to rise to 366 million globally by 2030 (Amir,2007). One of the measures of controlling this disease is daily monitoring of blood sugar level. The most common method of blood glucose level measurement involves pricking the finger which when done every day can be quite painful. Thus a non-invasive glucose monitoring device is a welcome alternative. The non-invasive blood glucose meter designed and fabricated in this study composed of a circuit consisting two LEDs of the same wavelength (LED pair) with one acting as a photo-emitter and the other as a photodiode photo-detector. Several LED pairs of different colors were tested for sensitivity to different glucose concentrations. Finger phantom tests were also done on the best LED pair. Out of all the LED pairs tested, the one that exhibited marked sensitivity to different glucose concentrations was the near-infrared LED (NIR-LED) pair with wavelength of 1450nm. The NIR-LED pair showed consistently increasing trend on the output voltage vs. glucose concentration (Chua and Gonzales,2013).

Key Words: glucometer; non-invasive; LED pair; non-invasive glucometer

1. INTRODUCTION

Diabetes mellitus more commonly known as diabetes has been an on-going problem around the world for many years now and the number of diabetics is expected to rise 366 million globally by 2030. In the USA this is the sixth leading cause of death in 2002 (Amir, 2007), and in the Philippines Diabetes is one of the top five causes of death for people between 60 to 64 years of age and between people aged 65 to 69 years (Virola, 2011)].

One of the measures of controlling this disease is to monitor it every day. Monitoring can be a very valuable tool for diabetics because they can plan their sugar intake for the day. This tight control of glucose levels is known to increase survivability of patients of diabetes and reduce their chances of complications (Amir, 2007). Monitoring blood glucose levels involves pricking the finger which when done daily can be quite painful and thus a good alternative is to use non-invasive glucose monitoring devices (Sia, 2010).

Non-invasive blood glucose monitoring devices have already been in development even as early as the year 2000 (see references). Infrared spectroscopy, more specifically, Near-Infrared Spectroscopy (NIRS) has been a powerful method to develop such devices and has been developed in many different labs (Malachoff, 2002). Non-invasive glucose monitoring devices can benefit not only the people suffering from diabetes but also those who still have normal levels of blood glucose concentration. If blood glucose monitoring can be done painlessly and inexpensively then it can be monitored regularly and can aid in the prevention of diabetes.

Non-invasive blood glucose monitoring is not yet a widely commercially available method of monitoring among diabetics. Photodetectors and spectrometers are very expensive and making glucometers using these isn't economically feasible. In this study, a glucometer was created using an LED as photo- emitter while another LED of the same wavelength was used as a photo detector. A total of 8 pairs of LEDs were used; red, orange, blue, green, white, ultraviolet, 1450nm Infrared LED, and an off-the-shelf IR LED. Several glucose concentrations were made and used for the testing of the device. A housing unit was built and used to serve as shielding for the cuvettes from ambient light sources as well as keeping cuvettes LED light source and detector aligned.

This study however will not include human testing but rather a test on a finger phantom. Unlike the other sources that this study was based upon, the research will only use a simple system that does not involve any programming.

2. METHODOLOGY

2.1 LED Pair (Photo emitter and detector)

The heart of the device is the LED, a semiconductor pn junction designed to emit light when forward biased. The frequency of the light emitted is related to its band gap (the difference of the lowest conduction-band energy to the highest valence-band energy). Different LEDs emit different photons of frequencies from the infrared to the visible spectrum depending on their band gap energy. The circuit below is the proper way of forward biasing an LED. A voltage higher than the built-in voltage of the diode is inputted to the circuit. The built-in voltage appears across the LED and the excess voltage across the resistor. The resistor determines the current through the diode thus its brightness. Normally a DC voltage is employed but a pulsating signal can be used to overcome the effects of ambient light.

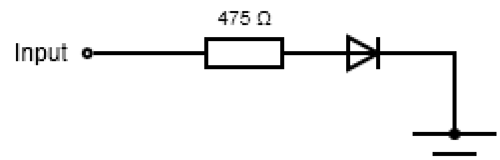


Fig 1. LED Photo-Emitter

The photodiode is also a semiconductor pn junction designed to receive light. It generates a photocurrent for received light whose frequency is proportional to its energy band-gap. Because the structure of the LED is the same as the photodiode, The LED can be made to function as an inexpensive photo detector. Moreover because an LED-pair of the same type have the same energy band-gap, we can perfectly monitor the photons emitted by the other. The need for a spectrometer is removed. But because the LED was not designed to optimally receive light, an electronic amplifier is needed to amplify the pico-amperes the LED generates. Below is the current-to voltage converter operational amplifier used. Note that the photocurrent which is comprised of minority carries actually goes out of the cathode instead of the anode. A capacitor may be placed in parallel to the resistor for a more stabilized reading (for a microcontroller instead of a professional VOM)

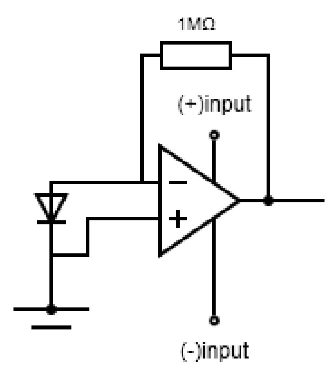


Fig. 2. LED Photo-Detector

The Paired Emitter-Detector LEDs were comprised of paired LEDs with different colors with one being the detector and the other being the emitter. A total of 8 pairs were used and in the study, the effectiveness of the different colors was also determined.

2-2 Test Samples

In the study, 3 ml plastic cuvettes were used to contain the glucose concentrations. Initially, the study featured two ranges, the normal range (0-180 mg/dl) and the hyperglycemic range (200-720 mg/dl). In these ranges, the data that was gathered were used to determine which of the LED pairs showed a consistent pattern that can be used. A second set was used (0-720 mg/dl) also to further show a general pattern. A third set which now involved a mix of blood and microspheres were used as finger phantoms. 8 cuvettes were made with blood of two volunteers (4 cuvettes for each volunteer). Each set had the same amount of microspheres, approximately 1 mg/dl, which was used to simulate the skin. 1 cuvette was used as a control control set-up; this did not have any glucose powder added. The other three had varying amount of glucose added which were 10, 80, and 150 mg/dl.

Fig. 3. Prepared glucose concentrations

Fig. 4. Finger Phantoms

The setup consists of a paired emitter-detector LEDs (of 8 sets of different colors) and their associated elctronics, The paired LEDs are brought to alignment in a housing unit where the prepared concentration of glucose in cuvettes and finger phantoms are inserted for testing. The pictures below show the setup.

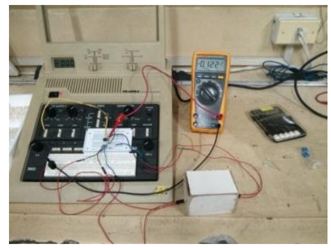


Fig. 5. Experiment Setup, the Glocometer

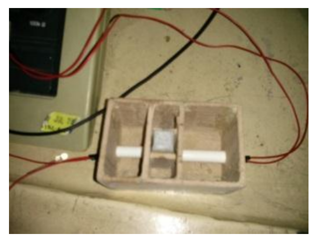
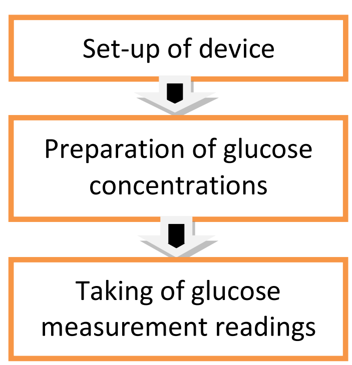


Fig. 6. LED-Cuvette Housing

The LED photo-emitter device was powered by 5-10 Volt DC supply. The resistor is set to control the brightness of the LED. The LED photo-detector is powered by a ±5V supply. To amplify the photocurrent, a current to voltage op amp was used. The gain that we used was 1 MΩ (i.e. Vout is the photocurrent multiplied by a factor of 10^6). A professional VOM was then used to measure the DCV output of the circuit. The housing unit was created, made up of board wood, for the purpose of keeping the cuvettes and LEDs in place and aligned during the readings. Also, the housing unit shields the setup from ambient light sources which could interfere with the readings.

2-3 Experiment Methodology



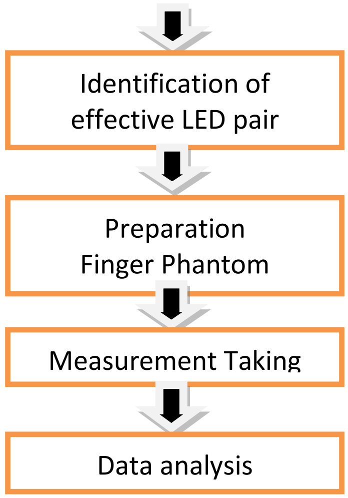


Fig. 7. Experiment Methodology

The first step for this study was to set up the device. It basically consisted of a paired emitter-detector LEDs, an op amp, and resistors all placed on a breadboard. The glucose solutions for testing were then created by combining glucose powder and distilled water together. Initially, there were two sets of concentrations one representing the normal concentrations and the other the hyperglycemic concentrations. After mixing thoroughly, the solutions were then placed on a labelled cuvette. This step was then repeated with increasing glucose concentrations. The cuvettes were then tested with several LED pairs and the results were graphed. The LED pair that showed a consistent pattern in both ranges was then tested in a continuous range (test 2) then tested with the finger phantoms (test 3). The data would then be graphed and analysed.

3. RESULTS AND DISCUSSION

A total of eight pairs of LEDs were used; Red, Orange, Green, Blue, White, Ultraviolet, and two pairs of infrared LEDs. Each pair was tested using the setup, to check for which pair would be deemed effective for use. Initially two ranges of glucose concentrations were used; 80-180 mg/dl concentrations with increments of 5 mg/dl (Normal Range), and 200-720 mg/dl concentrations with increments of 20 mg/dl (Hyperglycemic Range).

The paired LEDs of colors Red, Orange, Green, Blue, White, Ultraviolet and the Infrared LED bought from a local electronic shop (with unknown specifications) did not exhibit any noticeable pattern. The patterns for Red are shown below as representative of these.

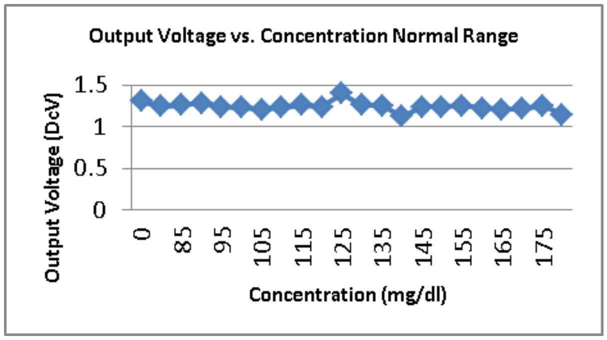


Fig.8. Red LED Pair Results – Normal Range

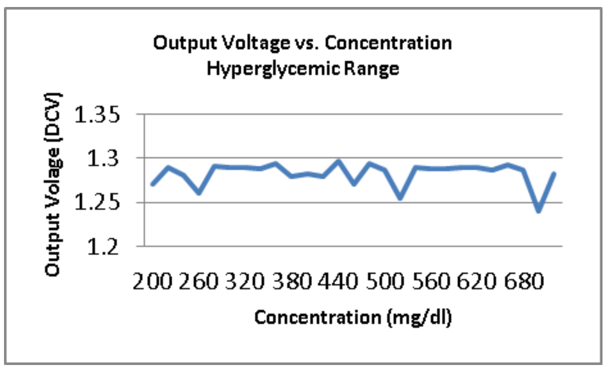


Fig. 9. Red LED Pair Results – Hyperglycemic Range

The infrared LED with wavelength 1450 nm exhibited a trend as shown in the next column.

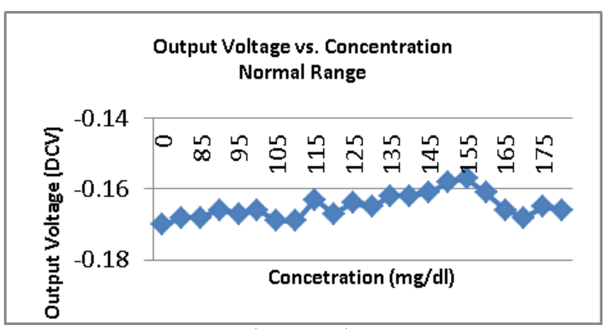


Fig. 10. Infrared (1450nm) LED Pair Result
Normal Range

It could be seen with the range of normal glucose samples that there is a very strong upward trend but with some dips. With a very high gain, op-amp characteristics would have to be taken into consideration as small offset currents will also be magnified with the same gain. The same trend can also be seen with the hyperglycemic glucose samples as shown below

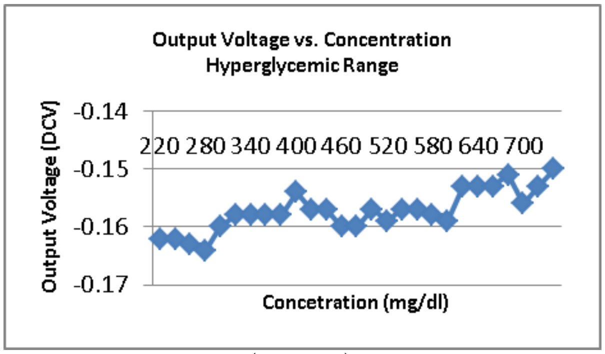


Fig. 11. Infrared (1450nm) LED Pair Result Hyperglycemic Range

From the initial testing the LED that showed the best pattern was the Infrared LED with a wavelength of 1450 nm. In this phase of testing a new set of glucose concentrations were used. The rage was from 0-720 mg/dl with increments of 30 mg/dl. This was to show a continuous transition from hypoglycemic to hyperglycemic and to confirm in one graph the effectiveness of the LED. Three trials were done to verify if the trend remains true. All three trials show a general increasing trend. A sample trial is shown on the next page.

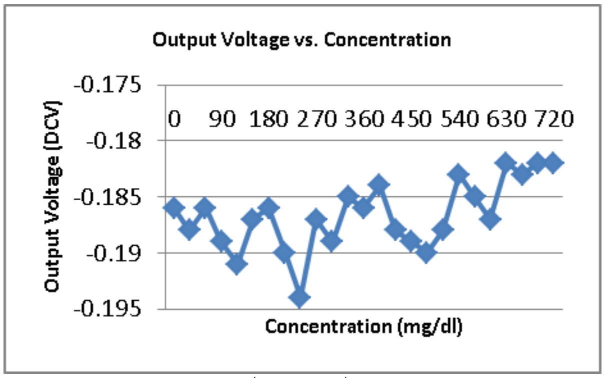


Fig. 12. Infrared (1450nm) LED Pair Result Continuous Range, 2nd Test

The finger phantoms were used for this last phase of testing to see if the expected readings still holds true for the finger phantom test. In this test, there were two volunteers whose blood was used for the finger phantoms. Four cuvettes per volunteer were used to determine the readings. Sample tests are shown below.

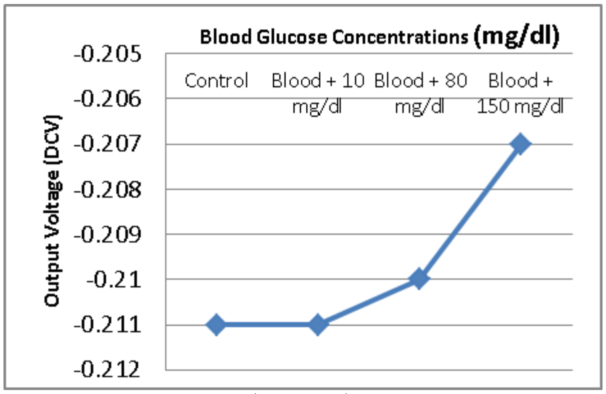


Fig. 13. Infrared (1450nm) LED Pair Result Finger Phantom Test 3-A

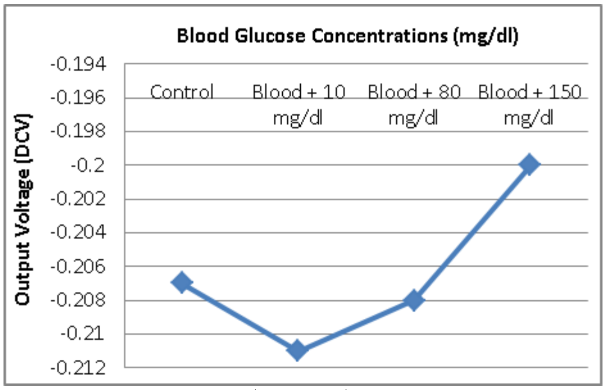


Fig. 14. Infrared (1450nm) LED Pair Result Finger Phantom Test 3-B

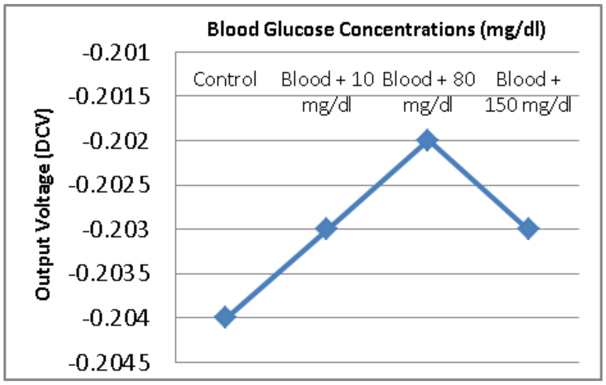


Fig. 15. Infrared (1450nm) LED Pair Result Finger Phantom Test 3-C

The results thou generally showing an increasing trend was not conclusive. Test 3-A showed the pattern while tests 3-B and 3-C showed a deviation. Is something else in the blood other than the glucose strongly interacting with the infrared light? Is it a problem with the electronics or the detector? Further experimentation is needed.

4. CONCLUSIONS

The study utilized a three-phase set-up that consisted of an initial testing of LED pairs of different wavelengths on different glucose concentrations, a 2nd glucose concentration test and a finger phantom test. The system utilized is a modified version done in a study by De Leon and Gaw (De Leon, 2010), who utilized the near IR LEDs and a spectrometer and by Sia (Sia, 2010), who utilized and IR LED emitter and a photodiode photo-detector integrated in a circuit with a microcontroller. Unlike theirs, the study utilized a circuit with two LEDs of the same wavelength with one acting as a photo-emitter and the other as a photo-detector. The device was simple enough to make and does not require very expensive components thus making it inexpensive. Out of all the LED pairs tested, the most effective pair was the NIR-LED pair with a wavelength of 1450 nm. The pair showed a consistently upward trend in the graph compared to the other LED pairs that had very variable changes.

The study clearly demonstrates that an inexpensive infrared LED pair (1450 nm), one used as a photo-emitter and the other as the photo detector can be used in a non-invasive blood glucometer. To minimize the effect of the electronics in such a high gain application it is recommended to find a more sensitive semiconductor photo-detector that does not require an amplifier. As of the time of publication of this article, such an inexpensive pair has already been identified by the senior team members and is currently being investigated. The results of this should give us a better understanding of the inconsistencies of test 3.

5. ACKNOWLEDGMENT

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6. REFERENCES

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