WIRELESS SMARTPHONE GLUCOSE MONITORING SYSTEM

Jeshurun Rojas [1], Allen De Guzman[2], Allison Gungon[3], Kyle Tristan Lapuz[4], John Peter Ramos[5]
Ira Valenzuela [6]
Technological University of the Philippines Manila, Philippines
[1]rojasjeshurun@yahoo.com
[2]allendeguzman13@gmail.com
[3]alliagungon@gmail.com
[4]ktlapuz@gmail.com
[5]johnpeterramos@ymail.com
[6]valenzuela.ira12@gmail.com

ABSTRACT

This study presents a mobile, Arduino-based blood glucose monitor which uses wireless communication via Bluetooth between the device and a smartphone to facilitate the management of chronic disease - diabetes. The glucose management system is capable of calculating required bolus intake with built-in recommendations. The system stores a database file in the external storage of the smartphone to manage personal glucose level records which can be sent via SMS. Voltage readings were measured electrochemically from blood samples extracted from test subjects via pin-prick method and processed through variable relationship and wireless connection procedures. Glucose readings were computed using basic statistical methods done by the Arduino microcontroller using voltage-glucose correlations. Thirty samples of blood were tested; divided into ten test subjects with three trials each. The prototype was observed to provide an accuracy of 100%.

Keywords: Bluetooth, Diabetes, Smartphone, Device, Glucose meter, SMS, Electrochemical

INTRODUCTION

Diabetes is one of the most widespread chronic diseases that always have been a public issue in the Philippines. This metabolic disorder results from pancreas not working properly and insulin deficiency and is reflected by blood glucose concentrations higher or lower than the normal range of 70-130 mg/dl [1]. The disease is one of the leading causes of death and disability in the world. The complications of battling diabetes are numerous, including higher risks of heart disease, kidney failure, or blindness [2]. Such complications can be greatly reduced through stringent personal control of blood glucose. Continuous glucose monitoring has been shown to help diabetic patients stabilize their glucose levels, leading to improved health. Hence, a glucose meter, capable of continuous real-time monitoring, has been a topic of research in the field of biomedical engineering. Latest blood glucose monitoring systems that offer the most convenient and efficient specifications (such as wireless and smartphone technology) among others poses a challenge about its availability in the Philippines. Thus, there is the need of the fabrication of these kinds of glucose meters to cope up with the medical needs of patients with the ever-increasing health demand of the country.

A recent study focusing on personal diabetes monitoring system which integrates wearable sensors, 3G mobile phone, smart home technologies and Google sheet to facilitate the management of diabetes. The system utilizes wearable sensors and 3G cellular phone to automatically collect physical signs, such as blood glucose level, blood pressure and exercise data like heart rate, breathing rate and skin temperature [3]. Another study developed a wireless diabetes care running on the android platform and utilizes Bluetooth technology for it to be a tool for better understanding of patient's condition [4]. The main goal of this study is to provide a blood glucose monitoring device in the Philippines which utilizes wireless communication and Gizduino v4.1 microcontroller to process glucose readings with accuracy and convenience as well as the device being cheaper than other wireless blood glucose monitors commercially available.

METHODOLOGY

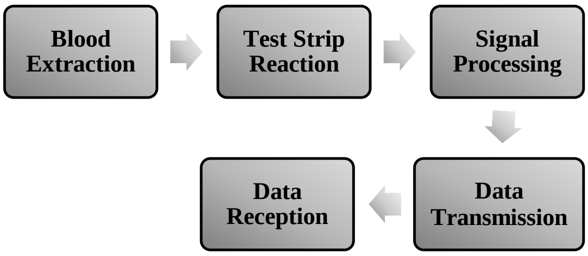

Figure 1 Main Block Diagram

The system is composed of five sections:

a) A. Blood Extraction

Blood samples were obtained from ten test subjects. To obtain the accuracy and precision of the device, five diabetic and five non-diabetic test subjects were gathered, and each person will be tested three times for precision test. Materials used for blood extraction are shown below.

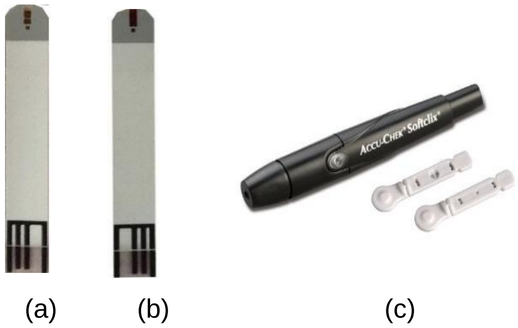

Figure 2 (a) Test Strip without Blood Sample (b) Test Strip with Blood Sample (c) Lancing Probe and Lancets

For acquisition of blood samples, a lancing probe is used to obtain a round drop of blood from your fingertip. When an adequate amount of blood has formed on your fingertip, transfer the drop of blood to the narrow channel in the top edge of the test strip. Test strips and lancets must be disposed properly after use.

B. Test Strip Reaction

Glucose (C6H12O6) is a carbohydrate whose most important function is to act as a source of energy for the human body, by being the essential precursor in the synthesis of ATP (adenosine triphosphate) [2].Current glucometers use test strips containing glucose oxidase, an enzyme that reacts to glucose in the blood droplet, and an interface to an electrode inside the meter. When the strip is inserted into the meter, the flux of the glucose reaction generates an electrical signal. The glucometer is calibrated so the number appearing in its digital readout corresponds to the strength of the electrical current: The more glucose in the sample, the higher the number [5]. The presence of glucose oxidase catalyses the reaction between glucose and oxygen, which causes an increase in pH, decrease in the partial pressure of oxygen, and increase of hydrogen peroxide because of the oxidation of glucose to gluconic acid:

$$\text{Glucose} + O_2 \xrightarrow{\text{Glucose Oxidase}} \text{Gluconicacid} + H_2O_2 \quad (1)$$

In the test strip, the enzymes are contained within the "reaction zone". When a blood sample is applied correctly, the enzyme and mediator compound transfer electrons to the electrode. This then bridges the gap between the electrodes and results in a rapid voltage drop. Once the voltage lowers until it reaches its predetermined threshold, the circuit switches to a constant voltage across the electrodes (400mV) [6]. If there is a 10% difference between the two electrodes, the application displays an error, requiring the user to insert a new strip. The current produced after the chemical reaction between the blood and the glucose oxidase will produce a small amount of current that is proportional to the glucose concentration sample.

C. Signal Processing

Current produced from the chemical reaction is amplified and converted into voltage using a Transimpedance amplifier. The resistance value can be calculated by using Ohm's law shown in Equation 2.

$$V = IR$$

where V = voltage output

I = current produced from the reaction

R = resistance needed for conversion

Because a mean value of 20µA is used, voltage is chosen to be 2 volts so that it is large enough to be used by the analog-to-digital converter [6]. Therefore the value of the feedback resistor is 100kΩ. The Gizduino v4.1 has an increased level of granularity with 32-bit quantization which gives good rendition of our analog signal [7]. From the output voltage of the amplifier, the microprocessor digitized this signal accurately, sampling different values closely to the next interval. The digital counts from 0-1023 bits are related to the input voltage through the use of a reference voltage of 5V. Equation 3 shows the function on how to convert a digital count to the actual voltage.

$$\text{Voltage} = \text{Digital Count in bit x} \frac{5V}{1024\text{bits}}$$

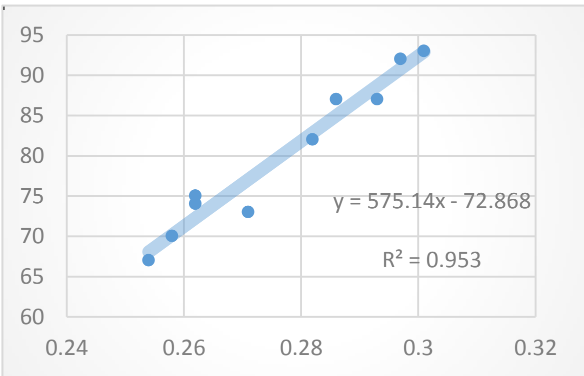

Figure 3 Glucose - Voltage Relationship

D. Data Transmission

EGBT-045MS is a 27x13mm Bluetooth module and will serve as our medium for sending data wirelessly. The Gizduino's Tx and Rx pins (Transmit and Receive) are used for Serial Communication or sending and receiving data. The Bluetooth module communicates with the Gizduino through these pins and transmits them to the receiver in the form of radio waves.

E. Data Reception

Any Android mobile phone with Bluetooth interface can communicate with this device. An Android application was provided to communicate with the device. User must pair the two devices first before taking any actions otherwise, no data will be received. The application consists of three features: (a) a database system storing glucose readings in a file, (b) a SMS feature that lets the user share his readings, and (c) an insulin dosage calculator with consultation system for recommendations.

PROJECT DEVELOPMENT

The device uses a Gizduino v4.1 microcontroller, an Arduino clone microcontroller, and an EGBT-045MS Bluetooth module (10m radius). The program is developed to transmit data wirelessly towards the smartphone using Arduino C and Android programming. The flow chart in Fig. 4 describes the operation of the whole system.

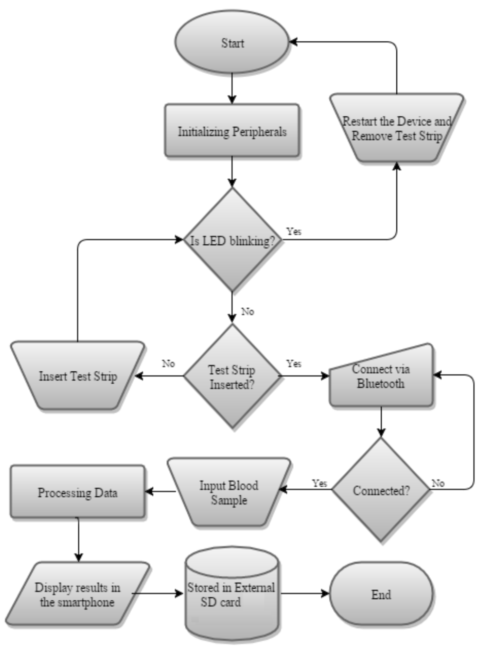

Figure 4 System Flow Chart

The program is capable of storing glucose readings in the external storage of the smartphone, providing reliable recommendations, and calculating required bolus intake. The device is rechargeable via micro USB connector/chargers.

Figure 5 WiGlu Exterior (2.5" x 3.5" x 1.25")

The main concern of the study was to develop a minimal cost and more convenient blood glucose monitoring device. This device was designed to measure glucose levels precisely and accurately. Unlike other latest wireless glucose meters today, which can graph the trends of the readings as well as storing it online; the device only covers manual reading of glucose levels and uses only local storage.

RESULTS AND DISCUSSIONS

A. Accuracy Test

The accuracy test was performed by comparing the mean values of the readings of the WiGlu over three trials with the readings of the Glucosure Autocode using the standard deviation of the commercial device. As presented, the ten samples corresponding to ten patients resulted to 10 out of 10 accuracy.

Table 1 Accuracy Table

Patient	WiGlu (mg/dl)	Glucosure (mg/dl)	St. Dev.	Accuracy
1	107	106	2.082	1
2	90	92	2.517	1
3	105	106	3.464	1
4	95	98	5.508	1
5	109	111	3.055	1
6	117	119	5.292	1
7	148	146	5.568	1
8	253	265	21.127	1
9	444	441	12.461	1
10	217	206	18.009	1
Total: 10				10/10 = 100%

Figure 6 shows the accuracy of the WiGlu by comparing it to the commercially available glucose meter.

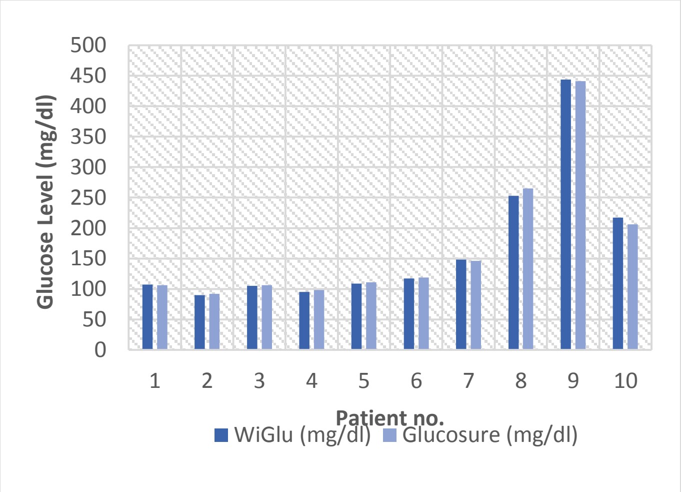

Figure 6 Accuracy Graph of the device

B. Precision Test

Using F-test Two Sample for Variances on Microsoft Excel, the difference between the variances of the two devices is compared.

Table 2 F-test using MS Excel

F-Test Two-Sample for Variances		
	WiGlu	*Glucosure*
Mean	5.6771	7.9083
Variance	13.00220721	46.87632534
Observations	10	10
df	9	9
F	0.277372578	
P(F<=f) one-tail	0.034845094	
F Critical one-tail	0.314574906	

As shown in Table 2, WiGlu has variance of 13.002, which is much less than the 46.876 variance of the commercial device. This denotes that the preciseness of WiGlu is accepted and more improved than that of the commercially available Glucosure Autocode.

CONCLUSION

The development of a glucose monitoring system which utilizes wireless serial communication between Arduino and Android via Bluetooth technology was successfully implemented. The system was able to measure the glucose levels of blood samples, and provided improved precision of 13.002 compared to 46.876 of the commercially available device and an accuracy of 100%. It is, therefore, proven that its use of wireless smartphone technology did not serve as a contributing factor to affect the device's readings.

The project was successfully done and proven to provide accurate results; however, the researchers suggest the following recommendations to further improve the project: (1) an online website database to lessen the hassle of collecting records and (2) the fabrication of its own test strip and test strip port to reduce cost.

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