Non-Invasive Glucose Meter for Android-Based Devices

Mon Arjay Malbog
Computer Engineering Department
Mapua University
Intramuros, Manila, Metro Manila Philippines
malbog.monarjay@gmail.com

Noel Linsangan
Computer Engineering Department
Mapua University
Intramuros, Manila, Metro Manila Philippines
nblinsangan@mapua.edu.ph

ABSTRACT
This study helps in monitoring blood glucose level of a patient with the aid of an android device non-invasively. Diabetes is a metabolic disease characterized by high level of sugar in the blood, and considered as the fastest growing long-term disease affecting millions of people globally. The study measures the blood glucose level using sensor patch through diffused reflectance spectra on the inner side of the forearm. The Arduino microcontroller does the processing of the information from the sensor patch while the Bluetooth module wirelessly transmits to the android device the measured glucose level for storing, interpreting and displaying. Results showed that there is no significant between the measured values using the commercially available glucose meter and the created device. Based on ISO 15197 standard 39 of the 40 trials conducted, or 97.5% fell within the acceptable range.

CCS Concepts
Computer Systems Organization → Embedded → Embedded Systems → Real time Embedded Systems

Keywords
Blood Sugar, Glucose Level, NIR LED, Photodiode, Sensor Patch

1. INTRODUCTION
Diabetes is the fastest growing long-term disease that affects millions of people worldwide. A diabetic person has high level of sugar in the blood, either because insulin production is inadequate, or because the body's cells do not respond properly to insulin, or both in a metabolic disease. To understand diabetes, it is important to understand the normal process of food intake for the body's energy. When a person intakes food glucose enters the bloodstream and serves as the fuel for the body. Insulin moves glucose from the bloodstream into cells. If glucose were not remove from the bloodstream, it causes high blood sugar that result in diabetes. Commercially available glucose meter offers patient to take down glucose readings manually and cannot store glucose readings nor interpret them if low, normal or high.

Monitoring the glucose level requires sample blood through finger pricks for each test, which causes pain and inconvenience. Each test also requires a new test-strip. Based on the features of glucose meter today, there are functions that need to improve to make the monitoring of blood glucose painless and convenient to use. Glucose meter is a necessity for a diabetic person and should be accessible anytime. There are various technologies available today for innovating commercially available glucose meter. This study aims to create a glucose meter that reads blood glucose level non-invasively, transmits information wirelessly to an android device and stores and interprets the readings made.

According to International Diabetes Federation, the different classifications of diabetes are type-1 and type-2. Type one diabetes is insulin-dependent accounting for about 5 to 10 percent of all diagnosed diabetes and is less common. Type-2 diabetes is non-insulin-dependent diabetes mellitus or adult-onset diabetes [1] and requires planning the meals toward controlling the blood sugar and weight. According to the American Diabetes Association, along with healthy eating, one can keep blood sugar in target range by maintaining a healthy weight. Persons with type-2 diabetes are often overweight. Losing just 10 pounds can help manage diabetes better. Eating healthy foods and staying active can help one meet and maintain the weight loss goal [2]. Mathew Bularzik designed a microprocessor-based glucose meter that communicates with the user interface and allows the patient to control what function the meter is performing [3].

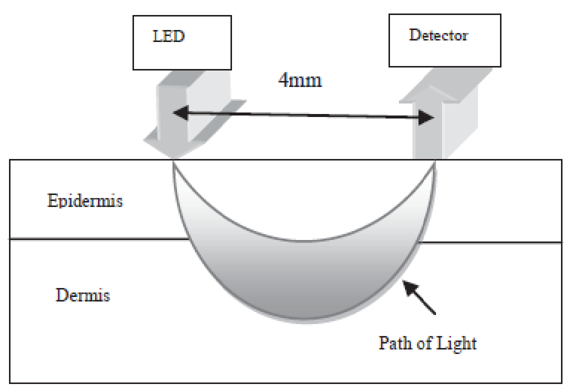


Figure 1. Schematic of cross section area of skin layers and light path using NIR [4]

In another study of S.S. Mule et al, they used 8051 microcontroller to measure blood glucose level [13]. According to Jyoti Yadav, optical methods are one of the painless and

ICCAE 2018, February 24–26, 2018, Brisbane, Australia

ACM ISBN 978-1-4503-6410-2/18/02…$15.00
DOI: https://doi.org/10.1145/3192975.3192979

promising method that is used for non-invasive blood glucose measurement. Near infrared (NIR) is one of the most widely explored optical techniques because of its high penetration capability in skin. This technique is applicable on various body parts: finger, palm, arm, forearm, and earlobe [4]. According to the American Association of Diabetes Educators, blood glucose monitoring provides immediate feedback on the effects of daily activities such as taking medications, exercise, or eating. A further study addressed by the team from the University of Connecticut Biomedical Engineering indicated that diabetes is a disease that currently affects 14.6 million Americans, comprising 6.3% of the American population. It is the fifth leading cause of death in the United States [5]. According to a World Health Organization report, globally, in 2014 an estimated 422 million adults were living with diabetes [14] and the count is increasing daily.

A study used photodiode to detect the attenuation of radiation due to changes in the glucose concentration. The study implemented monolithic photodiode/preamplifier 8-pin DIP package or OPT101 [6]. The American Diabetes Association defines diabetes as a metabolic disorder primarily characterized by elevated blood glucose levels and by micro vascular and cardio vascular implications that substantially increase the morbidity and mortality associated with the disease and reduces the quality of life [7]. In addition, diabetes has long been viewed as a disorder of carbohydrate metabolism due to its hallmark feature of hyperglycaemia [15]. Table 1 shows the recommended target for blood glucose levels by the International Diabetes Federation for adults with type- 1 diabetes, type-2 diabetes and for people without diabetes [8].

One study states that the concentration of glucose in blood is measured using an invasive technique by puncturing finger to take few ml of blood. In recent practice less than a drop of blood is needed and passed through the standard chemical tests to measure glucose concentration. This method is expensive as well as painful. The frequent finger puncturing causes calluses on the skin and increases the risk of spreading infectious diseases [9]. According to Ahmed Khan, diabetes is a condition where the pancreas of the body ceases to produce insulin, which controls blood glucose levels. The causes of diabetes among humans are not yet fully understand, but the widely accepted hypothesis is that it may be genetic and may be due to high sugar intake as part of a daily meal serving [10]. Applications development using appropriate programming language is easy and doable for almost all types of android-based device serving as graphical user interface [11].

Table I. Recommended Target Blood Glucose Level

Glucose Test	Normal	Prediabetes	Diabetes
Random	< 200 mg/dl	N/A	≥ 200 mg/dl
Fasting	< 108 mg/dl	108-125 mg/dl	≥ 126 mg/dl
2 hour post-prandial	< 140 mg/dl	140-199 mg/dl	≥ 200 mg/dl

2. METHODOLOGY

The study uses Waterfall method in developing the device. The waterfall life cycle as shown in Figure 2, is the natural way and the easier way of managing the development of the device to reach the expected outcome. This method also emphasizes the logical sequence of the steps needed in the development of the device as well as the cascading steps down in the incremental waterfall as shown in Figure 2. This method requires five (5) phases such as requirements planning, analysis, design, coding/construction and testing.

Data gathering is done by finding related studies about non-invasive glucometer applying spectroscopy sensor, the standard reading of glucose level and the computation for the blood glucose. These data help the researchers in formulating its objectives and scopes. Analysis identifies the major hardware components such as

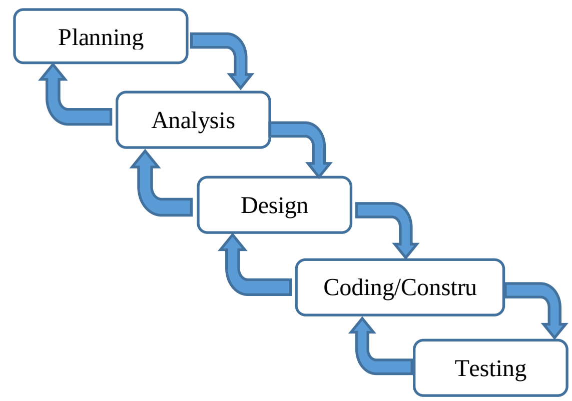


Figure 2. The Waterfall Methodology

sensors, microcontroller, android device as well as the programming language needed in the development of user interface. It also identifies the necessary inputs, processes and outputs. Design phase involves the development of the device. Figure 3 shows the architectural block diagram of the device. The sensor patch consists of a NIR spectroscopy sensor and a photodiode detector. The Gizduino processes the data coming from the patch sensor and transmits the processed data to the android device via Bluetooth.

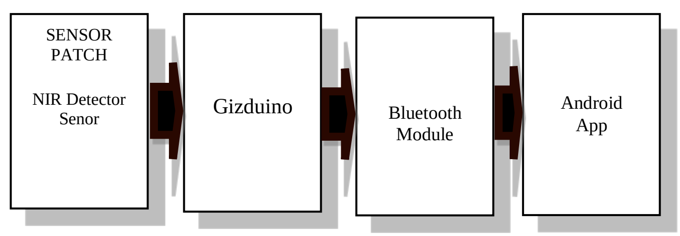
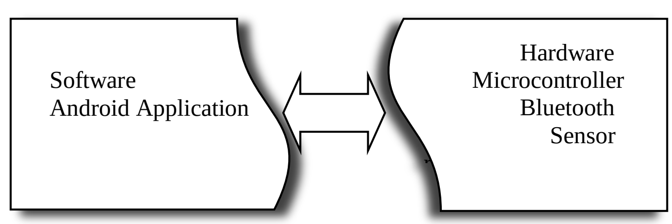


Figure 3. Architecture of the Device.

The android application also stores, displays and interprets the processed data. Coding/construction focuses on application development, circuit development and their integration. The android application uses Basic4Android android platform. Figure 4 shows the diagram of the integration of the created software



application for Android devices and the device hardware using Bluetooth and Gizduino microcontroller.

Figure 4. Integration between the Android Application and device hardware

The testing phase determines the acceptability of the results by comparing of the results between the commercially available blood glucose meter and of the created device. Forty subjects were used to complete the testing phase.

3. RESULTS

The initial results of the test conducted were very promising. Table II shows the initial results of the test conducted. The first column shows the number of trials conducted. The second column records the blood glucose levels using the market's invasive glucometer. The third column shows the device's readings through NIR sensor. The last column shows the correlated glucose level readings using linear regression by applying Equation 1. To investigate the sensitivity of NIR sensor patch, 40 subjects between 17 and 35 years of age were considered. From the recorded data in this table, 39 out of 40 results or 97.5% of the correlated data fell within the acceptable range defined by ISO 15197 standard. This standard requires 95% of the results should fall within the +/- 20% of the accepted value [12].

$$y = 74.529x - 103.14 \qquad (1)$$

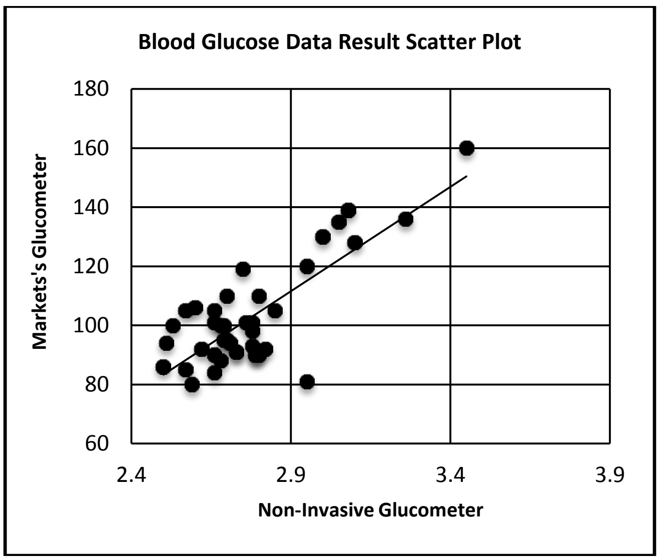


Figure 5. Scatter Plot of Commercially available Device vs. the Created Device

The scatter plot of the collected data is shown in Figure 5. Using the linear regression technique, the correlation value of the data between the x-axis and y-axis is equal to 0.842. This value suggested a strong positive correlation, which means that the increase of the Market's Glucometer (represented by y-axis) reading also increases the device reading (represented by x-axis).

The screenshots of the android user interface where the user can store, retrieve and view the results were shown in Figure 6. In addition, the application also determines if the patient's blood glucose level is normal or not based on acceptable standard. The application also stores other user information such as name, age and gender. For better appreciation of the results, bar graph was used to determine the progress of the blood glucose measurements. The stored data in the android device is retrievable and viewable for future reference.

Table II.
Blood Sugar Data and Results

Trials	Market's Glucometer	Non-Invasive Glucometer	Correlated Result
1	100	2.69	97
2	101	2.76	103
3	93	2.78	104
4	105	2.66	95
5	135	3.05	124
6	119	2.75	101
7	110	2.70	98
8	92	2.62	92
9	94	2.51	84
10	91	2.73	100
11	139	3.08	126
12	90	2.79	104
13	80	2.59	89
14	88	2.68	96
15	90	2.80	105
16	81	2.95	116
17	90	2.66	95
18	110	2.80	106
19	101	2.78	104
20	95	2.69	97
21	105	2.85	109
22	86	2.50	83
23	120	2.95	117
24	101	2.66	95
25	92	2.82	107
26	94	2.71	99
27	91	2.73	100
28	130	3.00	120
29	90	2.79	105
30	84	2.66	95
31	106	2.6	91
32	105	2.57	88
33	100	2.53	85
34	85	2.57	88
35	98	2.78	104
36	136	3.26	139
37	160	3.45	153
38	128	3.10	128
39	95	2.70	98

40	100	2.68	97

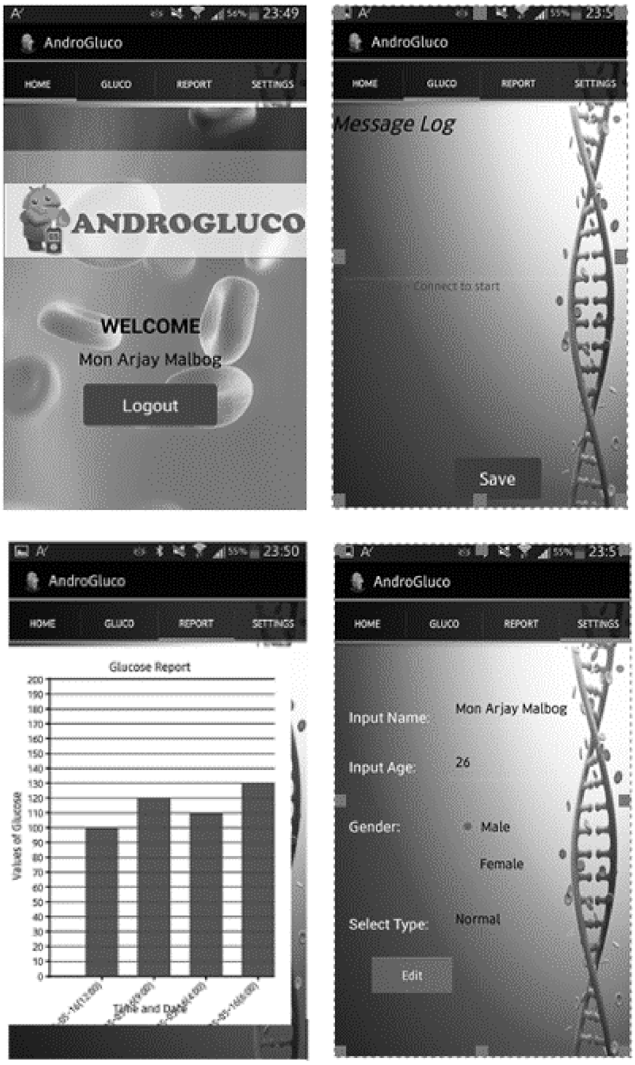


Figure 6. Sample Android User Interface

4. COCLUSION

Based on the data collected the following are the conclusions of this study. The data obtained using the created device were comparable to the data obtained using the commercially available blood glucose meter. The comparison was made using correlation by linear regression. The computed correlation coefficient of 0.842 suggested a positive strong correlation between the two sets of data which means that the two values are in the same direction. An up or down movement in the x-axis will cause a very similar movement in the y-axis. The data obtained by the user were successfully stored in the android device through the created application. These stored data in the android device are retrievable and viewable for future reference. In addition, the application also determines if the patient's blood glucose level is normal or not based on acceptable standard. Further, based on ISO 15197 standard, the collected results, 39 out of 40 trials conducted fell within the acceptable range of +/- 20% of the measured values using commercially available glucose meter. This represents 97.5%, above the 95% minimum requirement of the said standard.

For future works, the researchers recommend the use of technology other than NIR and photodiode detector for determining blood glucose level. In addition, improvements on the application program is recommended to include other operating system flat forms available such as IOS and Windows. Also, wearable devises can be created for the convenience of the user.

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