Design and Development of Amperometric Universal Glucose Meter System for Different Testing Strips

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***Abstract*— The purpose of this study is to design and develop a universal glucose meter device that could analyze different brands of testing strips. The functionality of the universal glucose meter is based on switching matrix and microcontroller .A small amount of current produced by the reaction of the blood sample with the glucose oxidase from the testing strips and it is used as its input. The input current will be incorporated into a signal conditioning circuit and it will be converted in terms of voltage, which will serve as input for the microcontroller. The microcontroller unit will allow the read and analyze the voltage level of the blood sample and by using an equation obtained from the calibration of the testing strips, the glucose level is converted to mg/dL unit. A series of tests were performed to compare the results obtained from the designed universal glucose meter and the corresponding test strip. Overall, the test using the universal glucose meter showed acceptable accuracy. The development of this universal glucose meter will assist diabetic patients and clinics for testing glucose level using various testing strips on a single device.**

***Index Terms*— ADC; Amperometric; Glucometer; Microcontroller; Potentiostat; Switching Matrix.**

I. INTRODUCTION

Diabetes is a disorder wherein a body has a high glucose level due to the insufficient production of insulin .Diabetes can be further classified into to two types - type 1 and type 2 diabetes. Type 1 diabetes, also known as juvenile diabetes, is a condition wherein there is not enough supply of insulin in the body. Conversely, Type 2 diabetes is where the body does not react to the insulin it produces. [1]. The normal glucose level of an individual is ranging from 70-100 mg/dl. During the circumstances where the glucose level is high but, it is not enough to be diagnosed with diabetes, the condition is known as pre-diabetes.

The blood glucose level of a person with pre-diabetes is from 100-125 mg/dl and individual suffering from diabetes has a glucose level range of 126 mg/dl and beyond [2].

Blood glucose monitoring is a very important task for diabetic patients to enable proper medication and treatment. Thus this shows the significance glucose meter and its role among the large population of diabetic patients [1].

Unfortunately, commercially available glucometers require its own corresponding test strip to function; which makes it difficult to be tested if the supplies needed for it to work are not available in a local pharmacy or in a public health care service [2-3]. The need for a universal glucometer is one of the issues needed to be addressed in the engineering and health field to help out diabetic patients be able to monitor their blood glucose easily by using any available testing strip.

Work done by Miyashita [4] has demonstrated the usage of a micro-planer amperometric biosensor for monitoring glucose level based on a urine sample. Work done by Chung [5] has shown the usage of readout circuit with potentiostat for the application of glucose meter. Work done by Demir [6] has shown the employment of amperometric biosensor to evaluate the performance of the glucose meter. Work done by Sarmaga [7] has demonstrated the utilization of various disinfectants on the performance of the glucose oxidase based glucose meter. All the reported works were based on improving the detection of the glucose meter. However, there was minimal evidence of work done on developing a glucose meter which could analyze the glucose concentration on the various type of commercially available testing strips.

Thus, the purpose of this paper is (1) to design and develop a universal glucose meter that accepts glucose testing strips of different brands. In particular, it intends (2) to design and create a glucose meter system that has a switching matrix to allow the user to select the brand that is specific with his glucose test strip, a signal conditioning circuit to manipulate the signal obtained from the reaction of blood glucose and glucose oxidase on the test strip, and a program for a microcontroller unit for the calibration and measurement of the blood glucose level. Finally, (3) it intends to conduct an experiment using the universal glucometer to test for accuracy and precision.

The direct recipient of the universal glucose meter will be the diabetic patients who can barely afford to monitor their blood glucose regularly through house testing because of difficulty getting test strips. Various home cares and clinics can largely benefit from the universal glucose meter as well because they can easily use the glucometer with whichever testing strip they have directly available to control the blood glucose of their diabetic patients. Since testing strips will no longer be a hindrance for the universal glucometer, the wellness of diabetic patients is constantly monitored and thus helps them prevent serious complications that may further arise from diabetes.

Commercially available glucometers have different features and specifications depending on the manufacturer. Based on the authors' survey on different drug stores, many glucometers have common features like the testing time, blood sample volume, memory capacity, averaging function, measuring range and the lancets and lancing device. The features of the different products only differ on its operating value that is limited to the device due to different specifications manufacturers used in each device. Due to the many different glucose meters existing nowadays, the device designed in this paper is limited to the glucose testing strips and glucose meters available in the market, particularly three of those meters and strips (One Touch Ultra, Easy Mate, and Advan), and the capability to display measurement of blood glucose level from various users. It will also only consider a 1:1 relation, which is for a certain meter only one strip it is capable of using will be considered.

II. METHODOLOGY

This section gives the explanation on how the Universal Glucose Meter works. The input for the system is the human blood sample which will then be placed in the selected test strip. The user will have the option to pick which strip that will be used using the switching matrix. The authors selected One Touch Ultra (3 pins), Advan (3 pins), and Easy Mate (2 pins) for the strips that can be used in the system. The chemical reaction takes place between the blood sample and the glucose oxidase which will produce a small current. The current will be converted by using analog to digital converter (ADC) [8]. The ADC value is passed into the Microcontroller unit which will directly relate the value into its designated blood concentration in terms of mg/dL.

A. Design and Development of Amperometric Universal Glucose Meter for Different Strips

The study is initiated on researching and surveying different glucose meter brands available in the market. Next, the authors selected three different brands of glucose meter with testing strips. The selected glucose meters brands are One Touch Ultra, Advan, and Easy Mate. After doing so, the authors examined the pin configuration of each testing strip. Calibrating the testing strips was needed to know that characteristics of the testing strip. After, the authors designed and developed the Universal Glucose Meter circuit

B. Switching Matrix

The Switching Matrix [9] is composed of three transmission gate for each pin and NMOS in order to arrange and switch the input to have our desired output configuration for the input of the potentiostat circuit. CMOS technology is used in the matrix which is a combination of NMOS and PMOS. Figure 1 shows the schematic diagram for the switching matrix. For the switching to occur, NMOS will turn ON when the signal is "HIGH" and turned OFF when the signal is "LOW" on the other hand the PMOS will turn ON when the signal is "LOW" and turned OFF when the signal is "HIGH". The inputs pins in the switching matrix will have two possible paths but since the NMOS and PMOS of the transmission gate have one input there will only be one route to pass since the other path will be a closed switch.

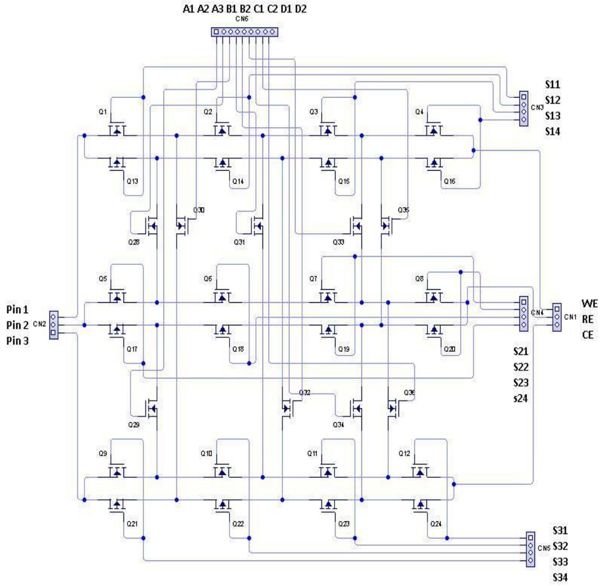

Figure 1: Schematic of the Switching Matrix

C. Potentiostat Circuit

Figure 2 shows the schematic diagram of the basic Potentiostat circuit. The circuit is specifically for the three pin testing strip. The potential from the reference electrode is then inputted in the first OP-AMP. After, the first OP-AMP compares it with Vin and will then be passed to the second OP-AMP for the control of the counter electrode. The working electrode is in the virtual ground.

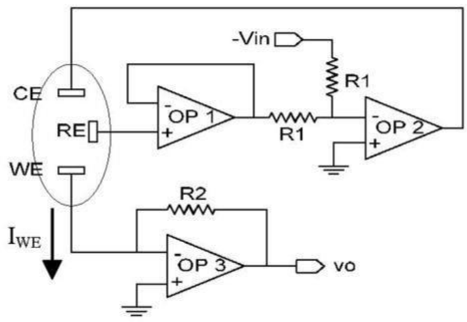

Figure 2: Basic Potentiostat Circuit

Figure 3 depicts a glucometer potentiostat in which three electrodes are used, which is a common set-up for studying redox chemistry [10]. Fundamentally, this circuit maintains a constant voltage difference between the working and reference electrode by using the counter electrode to sense changes in resistance between the reference and working electrodes and adjust the current accordingly. Therefore when the detected resistance is higher, the current will decrease and vice versa. The electrons from the oxidized mediator enter the LM358 current-to-voltage amplifier from the working electrode. The LM358 is a unity gain buffer amplifier, which serves as an interface between the circuitry with a high output impedance and the electrode with its low input impedance. Some current flows between the counter and the working electrode to ensure the oxidation and reduction reactions take place

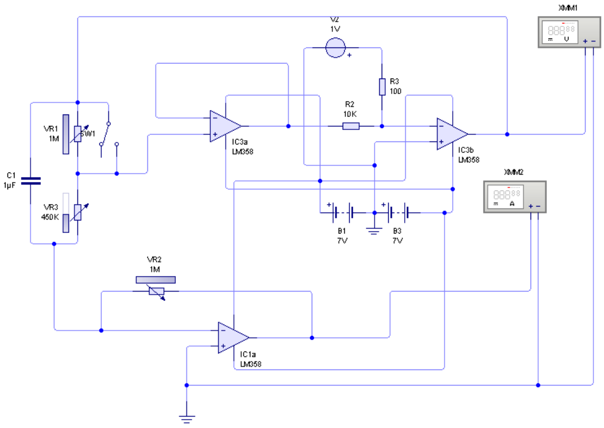

Figure 3: Schematic Diagram Potentiostat Circuit

D. Block Diagram of Universal Glucose Meter

The block diagram [10] in Figure 4 shows how the universal glucose meter functions. The system would start by turning on the power supply/battery. The three-electrodes of the Electrochemical Strip/Sensor of different brands have different configuration or pin assignment for their strips, therefore as the test strip enters the device, the pins go to the switching matrix and select brand and what type of pin configuration the test strip where the working electrode, reference electrode and counter electrode are arranged for the Potentiostat circuit where the calibration for each test strip occur and the output current of the different brands of test strip is converted to an ADC value. The Microcontroller unit converts the ADC value to an mg/dL value which determines whether the blood sugar level is low, normal or high and displays it on the LCD Display.

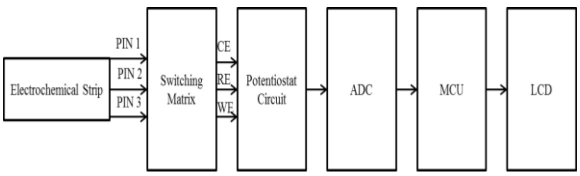

Figure 4: Block Diagram of the Universal Glucose Meter

E. Test Materials and Subjects

For this work, the capability of the designed Universal glucose meter was evaluated by using different test strips comprising of Easy Mate, One Touch Ultra, and Advan. In addition, the comparison was also made with the other existing glucose meter, namely Easy Mate, One Touch Ultra and Advan. In addition, the universal glucose meter in this work was tested on random subjects ranging from 24 subjects, 12 male and 12 females from the Mapua University campus site. For the testing, the subjects were grouped by 8 subjects per test (4 males and 4 females). Thus for all three strips testing, the subject tested were different. This was done to evaluate the performance of the universal glucose meter with a diverse range of subjects. During testing all subjects were in normal state and blood samples were taken from the edge of the index finger. However, the testing could not be carried out by using real diabetic patients as test subject due to the unavailability of ethical approval. Thus, this element will be tested and addressed in the near future.

III. Result and Discussion

In the laboratory, the authors prepared five different glucose concentrations as seen in Table 1, 2 and 3. These concentrations were each tested using One Touch, Advan and Easy Mates test strips, respectively, on the universal glucose meter device and their average ADC was taken and plotted to form the linear equation. The result from Table 1, Table 2 and Table 3 were plotted. The abscissa is the ADC values obtained from testing and the ordinate is the known concentration of the glucose. The equation was easily obtained afterward. The equation y=0.8259x + 50.039, where x is the ADC value and y is the concentration, is the equation for when One Touch test strips are used on the device. The equation y=1.0299x + 59.659 is the equation for when Advan and y=0.9061x + 25.587 is the equation for when Easy Mate test strips are used on the device.

Table 1
Results obtained from 5 Trials using One Touch Test Strips

One Touch	8-bit ADC					
Concentration (mg/dL)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
70	29	31	35	37	38	34
90	49	46	46	45	46	46.4
110	57	63	61	66	69	63.2
130	92	96	98	98	94	95.6
150	126	129	125	126	123	125.8

Table 2
Results obtained from 5 Trials using Advan Test Strips

Advan	8-bit ADC					
Concentration (mg/dL)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
70	18	19	17	18	19	18.2
90	25	24	26	26	25	25.2
110	43	51	47	41	40	44.4
130	68	65	61	70	65	65.8
150	90	89	93	97	90	91.8

Table 3
Results obtained from 5 Trials using Easy Mate Test Strips

Easy Mate	ADC					
Concentration (mg/dL)	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
70	37	44	42	45	47	43
90	74	79	77	80	79	77.8
110	90	93	97	95	99	94.8
130	110	113	117	120	118	115.6
150	135	140	132	137	142	137.2

Table 4 shows the comparison of the reading from the author's design versus the reading from One Touch meter. The percentage of error was computed to compare how accurate the result of the designed glucometer is to the commercial One Touch meter. Since the glucose concentration that resulted from the design did not stray too far from that of the commercial device, it can be said that the values obtained are valid and acceptable.

Table 4
Comparison of the Concentration of Glucose Measured from One Touch Ultra versus the Universal Glucose Meter

Subject	One Touch (mg/dL)	Design (mg/dL)	Percentage Error %
A	79	83	5.0633
B	107	99	7.4766
C	109	121	11.0092
D	64	69	7.8125
E	120	109	9.1666
F	110	101	8.1818
G	105	97	7.6190
H	94	104	10.6382

From Table 5, the comparison of the reading from the author's design versus the reading from Advan meter is shown as well as the percentage of error. Just like the results from the One Touch meter, since the glucose concentration that resulted from the design did not stray too far from that of the commercial device, it can also be said that the values obtained are valid and acceptable.

Table 5
Comparison of the Concentration of Glucose Measured from Advan versus the Universal Glucose Meter

Subject	Advan (mg/dL)	Design (mg/dL)	Percentage Error %
A	109	101	7.3394
B	142	138	2.8169
C	144	135	6.2500
D	110	104	5.4545
E	135	129	4.4444
F	124	135	8.8796
G	105	121	15.2380
H	99	109	10.1010

Table 6
Comparison of the Concentration of Glucose Measured from Easy Mate versus the Universal Glucose Meter

Subject	Easy Mate (mg/dL)	Design (mg/dL)	Percentage Error %
A	128	141	10.1562
B	142	132	6.3380
C	110	117	6.3636
D	120	126	5.0000
E	98	109	11.2244
F	121	126	4.1322
G	112	109	2.6785
H	122	111	9.0164

Table 6 shows the result obtained from comparing results from the commercially available Easy Mate meter to the designed glucometer. The results obtained are also valid and acceptable like the two previous comparisons because the values obtained from both did not have a huge difference. Table 7 shows statistical t t-Test: Paired Two Sample results for each testing strip vs universal glucose meter. Based on the absolute value of the t Stat is not greater than the critical two- tail and the probability that the null hypothesis is true is bigger than alpha (which is 5%), therefore the authors can accept the null hypothesis that there is no statistical difference between the each of the testing strips vs universal glucose meter. Thus, the result of the t-test for the three brands showed that there is no statistically significant difference from the data obtained from the three commercially available meters and the designed universal glucose meter.

Table 7
T-Test: Paired Two Sample for Each Testing Strip Vs Universal Glucose Meter

Statistical	One Touch	Advan	Easy Mate
t Stat	0.18907873	0.140620096	0.693481096
t Critical two-	2.364624252	2.364624252	2.364624252

IV. CONCLUSION

The meter was developed by having the switching matrix which was designed by considering all the possible combinations of the working electrode, reference electrode, and counter electrode that could arise from the electrode configurations of a 2-pin and a 3-pin test strip. The critical part of the research is the calibration of the three different brands of glucose test strips to obtain a standard equation for each that will be the sensitivity of the strip. Three unique linear equations were formed and programmed into the microcontroller. A series of tests were performed to compare results obtained from the designed universal glucose meter and the corresponding test strip, the result showed accuracy. By doing statistical analysis for the result from the series of test conducted, the objectives of this paper were completed.

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