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Analysis on Continuous Wearable Device for Blood Glucose Detection Using GSR Sensor

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ABSTRACT

This paper presents the development of a non-invasive approach to detect the blood glucose level using a galvanic skin response (GSR) technique. Previously, GSR had been used in many applications such as lie detector and emotion monitoring. GSR application on blood glucose reading has shown a promising potential detecting the blood glucose reading. The experimental study has been conducted to analyses the conductivity of the GSR sensor in order to find the correlation between skin conductance and the blood glucose level. The GSR sensor is used to measure the skin conductivity between two electrodes attached to the two fingers of the same hand and the electrodes are connected to the analogue input of the microcontroller to process the readings and display it. While taking a reading, the skin temperature and movement variation were minimized. The reading of GSR is taken on several samples throughout the day and compare with the reading taken by conventional finger pricking method. From the result, it shows a significant correlation between blood glucose level and GSR readings which inversely proportional to each other with correlation factor of 0.670.

Keywords: Galvanic Skin Response (GSR), Blood Glucose Level, Android Application (.apk), Firebase Database

1. INTRODUCTION

Diabetes is an incurable condition of human body with high glucose concentration in blood. Without a proper management of diabetes, it can lead to various complications including organs failure and even fatal [1]. Insulin is a hormone that helps lowering glucose concentration in the blood by storing the excessive glucose into the liver and other cells. Diabetes can be categorized into two types, Type 1 and Type 2. Type 1 occurred when the body loses the ability to produce an insulin while Type 2 occurred when there is a resistance to the action of insulin or the pancreas itself cannot make enough amount of insulin to overcome the resistance [1], [2].

There are three type of approach for blood glucose monitoring method as shown in Figure 1. It can either be using invasive, minimally invasive or non-invasive approach. In a current practice, diabetes patient must prick their fingers in order to draw the blood to measure their glucose concentration. The non-invasive method is a pain-free monitoring method and it is lowering the risk of infection due to their nature of measurement that did not required to withdraw the blood. Due to that, currently it is preferable to make a comparison between invasive and minimally invasive method. In addition, minimally invasive and non-invasive allowing a continuous

monitoring method using a wearable sensor that can be connected to smartphone or direct to the server and databased through an internet network [3].

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(a) (b) (c)

Figure 1. Blood glucose monitoring approach (a) Invasive; (b) Minimally Invasive; (c) Non-invasive

The galvanic skin response (GSR) sensor is known to measure human skin conductance [3]. The skin conductance can be influenced by a variety of factors, though the most important factor is, it needs to be measured with enough moisture on the skin surface [5] Originally, GSR sensor was solely used in the fields of psychology and psychoanalysis as a lie detector but it also has a potential to be applied into the fields of medicine including measuring blood sugar concentration [6], [7], [8].

Previously, there are a few studies and development that had been done for non-invasive device to monitor the blood glucose level [9], [10], [11]. A comprehensive review had been done on the sensors and the functionalities of non-invasive approach used in wrist wearable device [9], The study has reviewed that, there are three level of functionality differences in the wrist wearable device application. Each level is summarized in Table 1.

Table 1 Level of application for non-invasive wearable device in monitoring the blood glucose.

Level	Device Functionality
Level 1	The device is used only for tracking and/or logging the raw inputs from the monitoring activities. The device will not share the information with the user who wear the device.
Level 2	The device is used for tracking and/or logging the raw inputs from the monitoring activities. The output can be displayed back to the user through graphical user interface (GUI) form
Level 3	The device can provide an intelligent information to the user. The output is made up by some mathematical formulation or machine learning model. The device can transform the input to a variety of information and display to the user. The output can also be remotely stored and viewed in the cloud or other connected devices such as smartphone or computer,

Even though the non-invasive approach has been trendily developed among the researcher, the accuracy issue, device calibration issue and the standard device regulatory are still the most challenging matter to make this approach towards replacing the current practice [10]. By using GSR as a sensor to measure the sweat, this study is under categories of non-invasive: electrical bio-impedance (EBI) for Level 3 application for non-invasive wearable device for monitoring blood glucose. The advantages of this bio-impedance are that these methods are inexpensive, and easy to use it on the skin. Meanwhile, the disadvantages of the measurement taken might be influence by variations of temperature and motion of the hands while taking the results. At the same time, the sensor placement contributed towards the reading value as the sensor itself is quite sensitive to the amount of sweat and electrolyte content in the sweat itself.

This study aims to find the correlation between skin conductance and the blood glucose level while other factors such as skin temperature, amount of sweat and body movement are remained constant. This paper outline starting with the introduction section related to the topics and followed by the methodology of the overall process as stated in Section 2.0. Section 3.0 present the result and discussion and the last section is Section 4.0 explaining the conclusion of the whole study.

2. MATERIAL AND METHODS

The development of the GSR systems was divided into two parts, which are hardware and software implementation. For hardware part, a conditional circuit was built using GSR and temperature sensor to detect human skin conductance and skin temperature that has a correlation with blood glucose level. For the software part, microcontroller was coded to collect user data. A smartphone application was created to read the data send by microcontroller to the phone via Bluetooth 4.0.

1.1 Development of GSR system and circuit

The whole conditional circuit consists of two main part; the first part is the GSR sensor (detector) circuit for skin conductance measurement. The second part is a temperature sensor circuit which is used to measure the skin temperature of the user. The GSR sensor monitors skin conductivity between two reusable electrodes attached to the two fingers at the same hand. Figure 2 shows the overall schematic design of the hardware prototype.

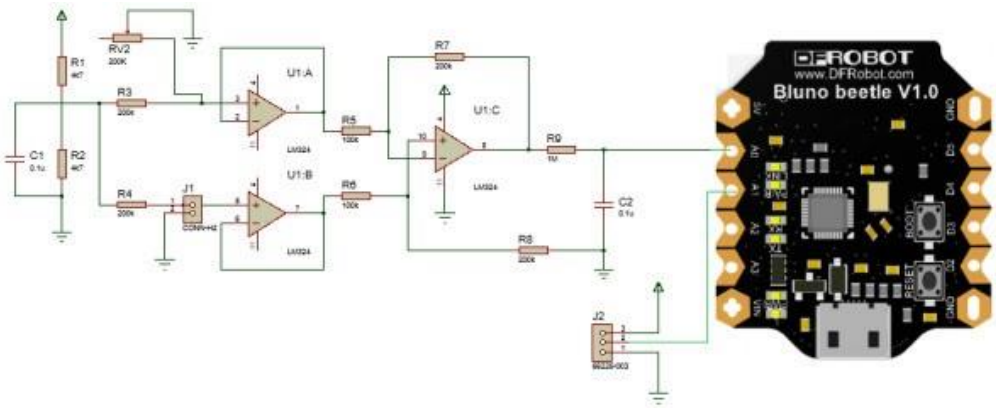

Figure 2. Schematic design of the hardware prototype

2.2 System application and database

Bluno Beetle microcontroller is programmed by using Arduino IDE environment. The microcontroller is coded to read the GSR and skin temperature measurement. The measurements taken by the microcontroller are sent to a smartphone for display purposes. The application (.apk) with the name of "GSR-BGL" is created and the main GUI of the created application is as shown in Figure 3

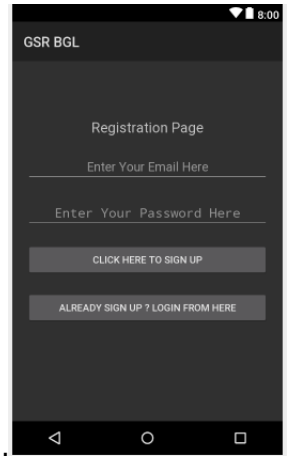

Figure 3. GSR-BGL application on Android application

Only the authorized person with email registered in GSR-BGL application can access the application. Each user will have an autogenerated of unique user ID as shown in Figure 4. Figure 5 shows, the real time measurement recorded to the cloud database stored under a specific user ID.

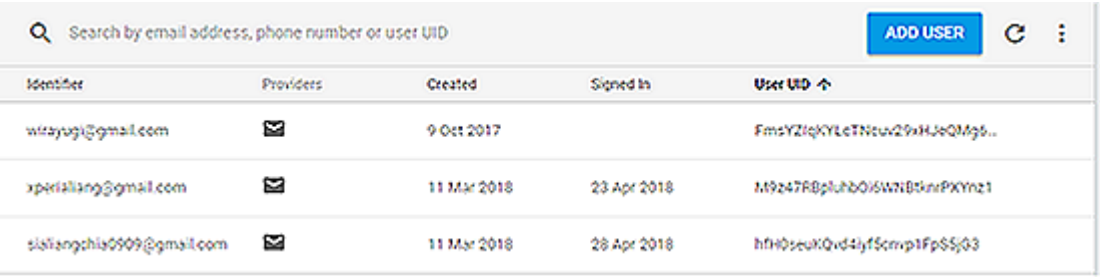

Figure 4. GSR-BGL email authentication on Firebase database

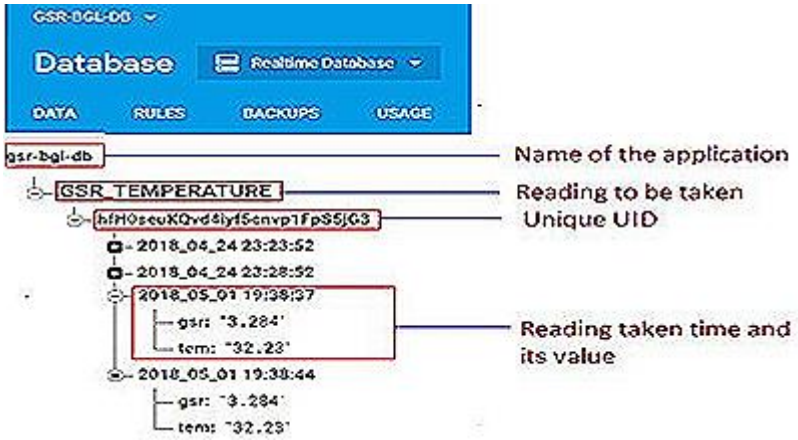

Figure 5. Firebase cloud database

3. RESULTS AND DISCUSSION

The GSR measurement was extracted from three nondiabetic persons. It is predicted to get the reading of the blood glucoses concentration to be less than 11 mmol/L as it is a common reading for nondiabetic person even after taking a food. This information is very crucial in order to plan a data intake for glucose reading in order to get a diversify variation of glucose concentration reading [6], [11].

Table 2 User's physical data

User	Age	Height (cm)	Weight (kg)
User 1	24	172	64
User 2	23	180	75
User 3	22	178	70

Table 3 Average of calories intake and calories burn for each user

Section / User	User 1		User 2		User 3	
Calories	Calories intake	Calories burnt	Calories intake	Calories burnt	Calories intake	Calories burnt
Morning	89	2.112	270	2.794	-	5.258
Afternoon	670	3.959	485	4.446	330	6.551
Evening	810	6.048	682	8.011	884	6.729

The physical information of all three subject is shown in Table 2. On the day of the experiment is running, subject calorie intake and calorie burn were estimated based on the types and amount of food as well as step count by referring to the calculator in Fitness and Health Calorie Calculator. Retrieved from https://www.calculator.net/calorie-calculator.html. The details of calorie intake and calorie burn for each user is shown in Table 3.

3.1 Pre analysis of subject's daily activity and its glucose reading affect

The analysis is made based on data collection on the user such as user's GSR value, number of steps, calories burn, skin temperature, calories intake and actual blood glucose level. These data are essential to schedule the measurement of the glucose consumption using a finger pricking method appropriately, as this method is mildly discomforting to be used repeatedly.

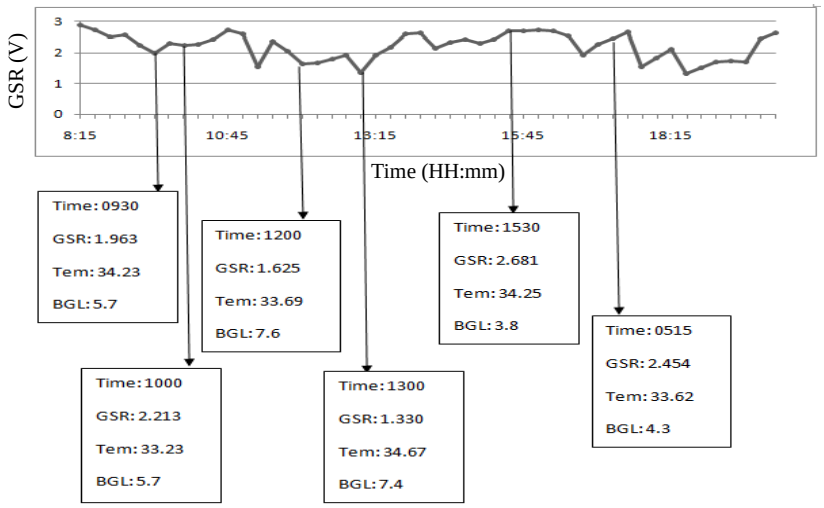

Figure 6. GSR graph with respective blood glucose level for User 1

The GSR sensor reading in voltage had been logged in every 15 minutes for 12 hours period continuously for all users. Figure 6 shows the GSR reading of User 1, taken throughout the days. The same measurement was repeated for User 2 and User 3. Within that interval, six samples of blood glucose level have been taken to be analyzed for the next experimental observation on finding a correlation between skin conductance and the blood glucose level.

Table 4 GSR Value with respective to Blood Glucose Level

GSR data (V)	Blood Glucose Level (mmol/L)	GSR data (V)	Blood Glucose Level (mmol/L)
1.963	5.7	1.293	7.1
2.213	5.7	2.035	5.9
1.625	7.6	2.693	5.3
1.330	7.4	2.492	5.8
2.681	3.8	1.676	9.4
2.454	4.3	1.394	7.0
1.966	7.1	2.013	6.8
2.192	5.9	1.303	7.3
1.408	8.8	2.682	5.1

Based on the plot in Figure 6, the blood glucose reading was up and down throughout the whole day and as we can see from the early observation of blood glucose and GSR readings, it shows that when the GSR value is decreased, the blood glucose reading is increased and vice versa. This indicate that the relationship between GSR and blood glucose level are inversely proportional to each other. This correlation is important in the process of predicting the value of the glucose reading based on the GSR value. Details on the correlation between GSR and blood glucose reading is further discussed in the next section.

3.2 Correlation between blood glucose concentration and GSR reading

The GSR value is measured by using the designed GSR system and blood glucose level was taken with the help of conventional glucometer using finger pricking technique. Table 4 is a collective data reading of GSR reading in voltage and its consecutive blood glucose level reading in mmol/L for all user taken several times throughout the day as stated previously in Figure 6.

By using data from Table 4, the graph in Figure 7 was plotted. After putting all the data point into the graph, a best fit line was formed with a linear equation below:

$$y = -2.233x + 10.83 \quad (1)$$

where the y variable represents the blood glucose level and the x variable represent GSR value. Based on the best fit line graph, it shows that there is a correlation between the GSR value and

the blood glucose level with correlation factor, R^2 is 0.670. This relation is important in order to predict the value of blood glucose level without needing to draw the blood pricking from the finger. With the value taken by using the developed GSR system measured in voltage and apply it in Equation 1, the value of blood glucose of users can be predicted. Minimizing the temperature of the skin and body movement variation while taking a reading, help in stabilizing the GSR readings and contribute to such of correlation.

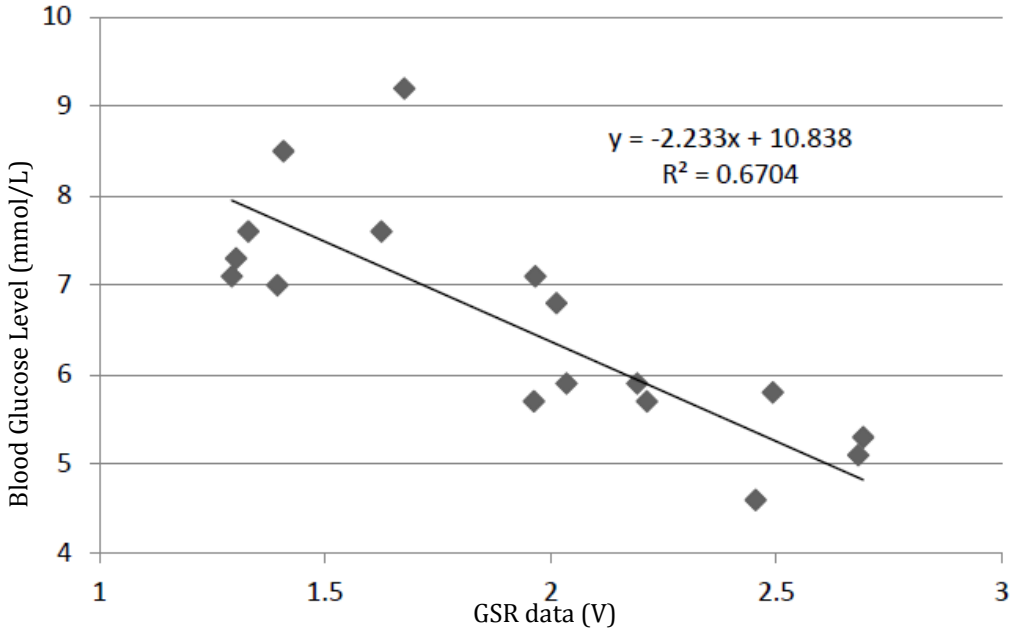

Figure 7. Correlation between blood glucose level and GSR readings.

4. CONCLUSION

At the end of the study, we manage to demonstrate a wearable embedded system device for continuous GSR monitoring. The device can be connected wirelessly to the smartphone with its application installed in it for display purposes. The correlation of blood glucose level and GSR data reading is determined as inversely proportional to each other with correlation factor of 0.67. This equation can be used for glucose reading prediction directly from GSR readings. It shows that GSR reading can be more stable by minimizing the variation of external parameters such as, temperature and hand movement while taking results reading. For future improvement, there are a few suggestions that can be done to improve the whole study. First improvement is by applying a light pleasure to the hand so that the measuring area can receive an equivalent compression to stretch the surface for a better constant reading. Secondly, by applying an indicator into the system such as a vibrator to the GSR device. It will help the user to stay still while the measurement is taking place.

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