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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 compared with the readings taken by the conventional finger pricking method. From the result, it shows a significant correlation between blood glucose level and the GSR readings which is inversely proportional to each other with the 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 the human body with high glucose concentration in blood. Without the proper management of diabetes, it can lead to various complications including organ failures and even fatality [1]. Insulin is a hormone that helps to lower 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 occurs when the body loses the ability to produce insulin whilst Type 2 occurs when there is a resistance to the action of insulin on the pancreas where it cannot produce enough amount of insulin to overcome the resistance [1], [2].

There are three types of approach to blood glucose monitoring method as shown in Figure 1. It can either be an invasive, minimally invasive or non-invasive approach. In the current practice, diabetes patients 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 lowers the risk

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of infection due to their nature of measurement that does not require to withdraw the blood. Due to this, currently it is preferable to make a comparison between invasive and the minimally invasive method. In addition, minimally invasive and non-invasive allow a continuous monitoring method using a wearable sensor that can be connected to a smartphone or direct to the server and databased through an internet network [3].

(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 were a few studies and development that had been done for non-invasive devices to monitor the blood glucose level [9], [10], [11]. A comprehensive review had been done on the sensors and the functionalities of the non-invasive approach was used in wrist wearable device [9], The study has reviewed that, there are three levels 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 wears 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 the graphical user interface (GUI) form
Level 3	The device can provide an intelligent information to the user. The output is made up ~~by~~ of some mathematical formulation or machine learning models. The device can transform the input to a variety of information and display it to the user. The output can also be remotely stored and viewed in the cloud or other connected devices such as the smartphone or computer,

Even though Although the non-invasive approach has been trendily developed among the researchers, the accuracy issue, device calibration issue and the standard device regulatory are still the most challenging matters to make this approach towards replacing the current practice [10]. By using GSR as a sensor to measure the sweat, this study is under the category 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 on the skin. Meanwhile, the disadvantages of the measurements taken might be influenced by variations in temperature and the 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 remain constant. This paper outline starts 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 results and discussions 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 the hardware and software implementation. For the hardware part, a conditional circuit was built using GSR and the 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 sent by the microcontroller to the phone via Bluetooth 4.0.

2.1 Development of GSR System and Circuit

The whole conditional circuit consists of two main parts; 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.

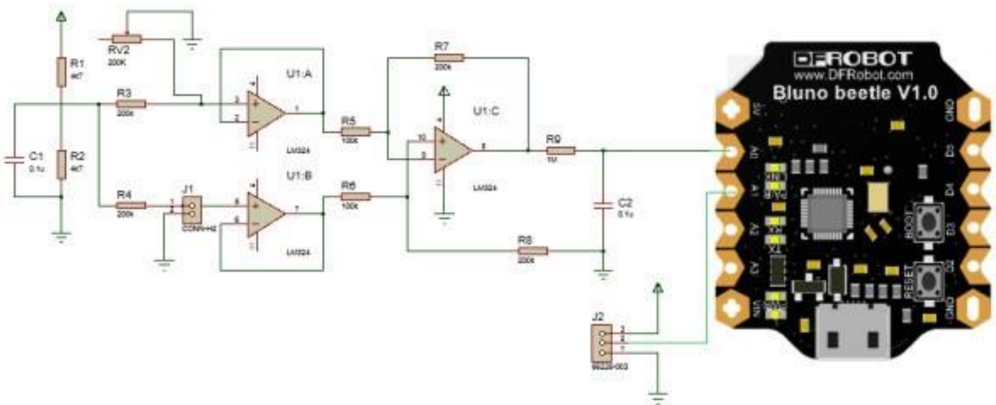

Figure 2. Schematic design of the hardware prototype.

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

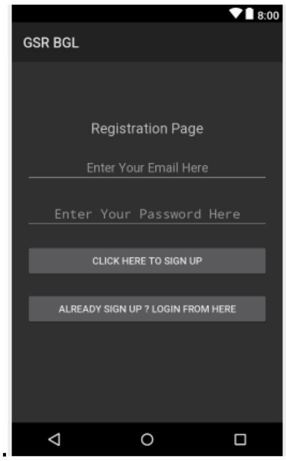

Figure 3. GSR-BGL application on Android application.

Only the authorized person with email registered in the GSR-BGL application can access the application. Each user will have an autogenerated 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.

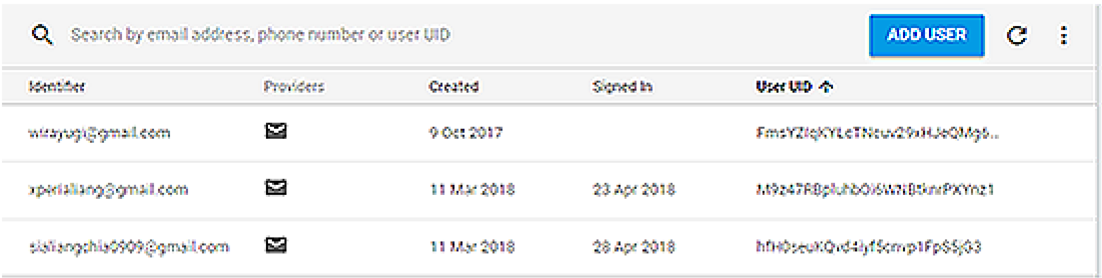

Figure 4. GSR-BGL email authentication on Firebase database.

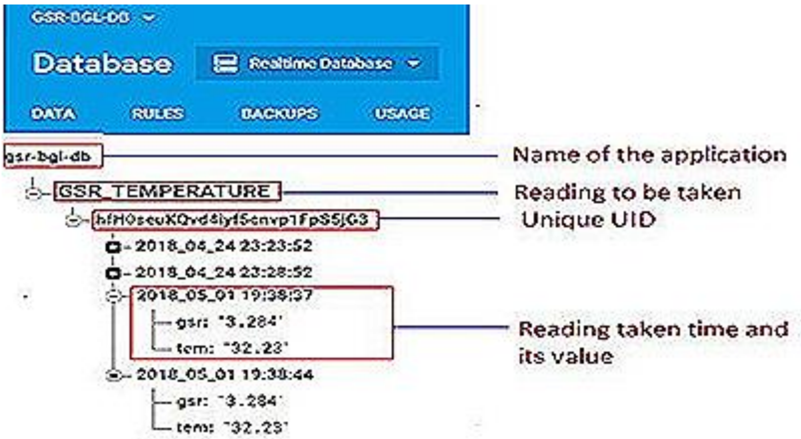

Figure 5. Firebase cloud database.

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 a 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 diversified variation of the 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 subjects is shown in Table 2. On the day the experiment was run, the subject's calorie intake and calorie burn were estimated based on the types and amount of food as well as the 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 the finger pricking method appropriately, as this method is mildly discomforting to be used repeatedly.

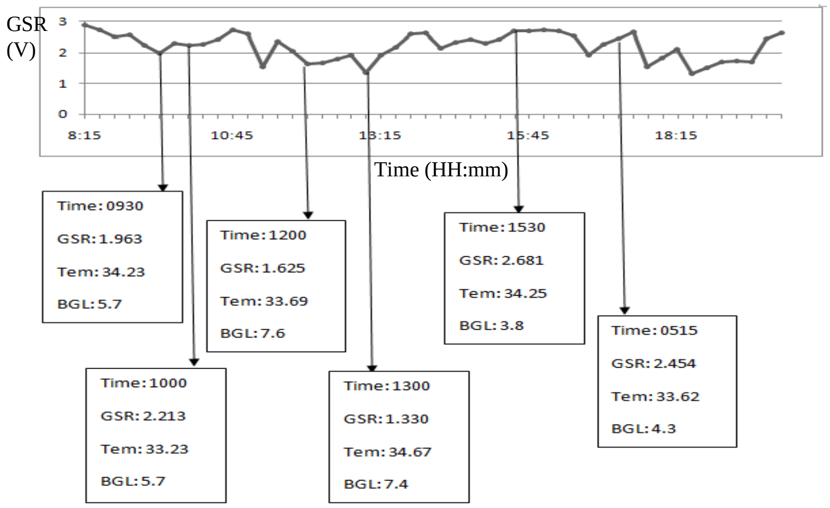

Figure 6. GSR graph with the respective blood glucose level for User 1.

The GSR sensor reading in voltage had been logged in every 15 minutes for a 12-hour period continuously for all users. Figure 6 shows the GSR reading of User 1, taken throughout the day. The same measurement was repeated for User 2 and User 3. Within that interval, six samples of the blood glucose level had 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 indicates 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 the conventional glucometer using the 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 users taken several times throughout the day as stated previously in Figure 6.

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

$$y = -2.233x + 10.83 \tag{1}$$

where the y variable represents the blood glucose level and the x variable represents the 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 the 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 applying it in Equation 1, the value of the blood glucose of users can be predicted. Minimizing the temperature of the skin and the body movement variation while taking a reading, help in stabilizing the GSR readings and contribute to such a correlation.

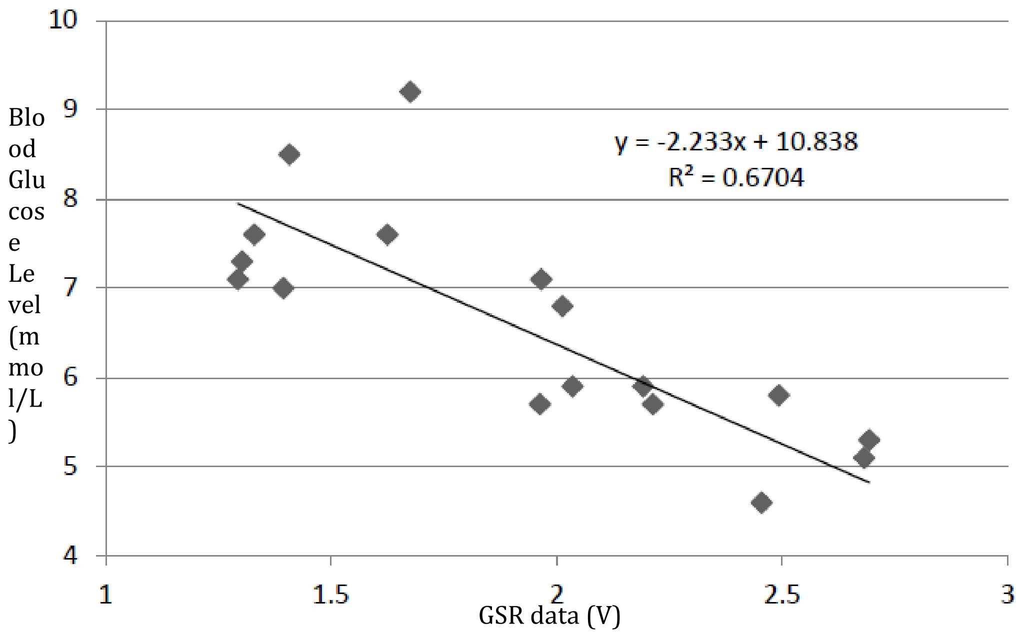

Figure 7. Correlation between blood glucose level and GSR readings.

4. CONCLUSION

At the end of the study, we managed 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 between blood glucose level and GSR data reading is determined as inversely proportional to each other with a correlation factor of 0.67. This equation can be used for glucose reading predictions directly from the GSR readings. It shows that the GSR reading can be more stable by minimizing the variation of the external parameters such as, temperature and hand movement while taking results reading. For future improvement, there are a few suggestions that can be used to improve the whole study. The first improvement is by applying a light pressure 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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