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Blood Glucose Device with XBee Wireless Protocol and MySQL Database for Diabetes Assessment and Monitoring

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The prevalence of diabetes has increased in both adult and young populations in the past few decades. Diabetes alone does not cause death, but its complications will. The complications of diabetes include cardiovascular diseases, nerve damage, kidney damage, bone and joint problems, and ketoacidosis. Therefore, a long-term monitoring of the blood glucose levels for diabetics and non-diabetics are important. This study designs a wireless blood glucose device with MySQL database for diabetes assessment and monitoring. A microcontroller circuit is designed to extract the value of blood glucose level from the blood glucose meter. The data is then transmitted into personal computer via XBee wireless module. Finally, MySQL database is used to store, manage and analyze the data obtained. This enables doctors to easily monitor their diabetes patients and comment on their blood glucose levels without meeting them personally. This has simplified the medical services and subsequently improve the efficiency of medical services.

Keywords: blood glucose; database; diabetes; wireless; health assessment; health monitoring

I. INTRODUCTION

The World Health Organization Diabetes Country Profiles 2016 reported that 3% of deaths in Malaysia are caused by diabetes and 36% of deaths are caused by cardiovascular diseases which are the major complications of diabetes (World Health Organization, 2016). Diabetes causes numerous of complications such as cardiovascular diseases, nerve damage, kidney damage, eye damage, foot damage, hearing impairment and Alzheimer's disease. Diabetes is not a fatal disease, but its complications can seriously affect our life.

Diabetes can be categorized into 2 types: Type 1 Diabetes and Type 2 Diabetes, with 90% of the diabetics are categorized under Type 2 Diabetes. Type 1 Diabetes can also be known as juvenile diabetes which is usually diagnosed in children. The pancreas of patients diagnosed with Type 1 Diabetes cannot function well, their body therefore cannot produce insulin. Patients with Type 2 Diabetes meanwhile, begin with insulin resistance, the body therefore does not give a proper response to control the blood glucose levels (Dansinger, 2019). The function of insulin is to allow the glucose to get into the cell. Without the help of insulin, the glucose cannot be diffused into cells and this causes high blood glucose level in the blood. Type 2 Diabetes can be prevented in physical way. Increase in weight will increase the chance to get the Type 2 Diabetes. To prevent it, one should lose weight and keep it off. Besides, keeping exercise at least 30 minutes and work for 5 days a week can also help to prevent Type 2 Diabetes (Colberg *et al.*, 2016).

In this study, the researchers propose a wireless blood glucose device with database for diabetic's health assessment and monitoring. A microcontroller circuit is designed to extract the value of blood glucose level from the blood glucose meter and transmit the data into personal computer via XBee. A software connected to database is designed to store, manage and analyse the data.

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The objectives of this study are: (1) to propose a device to simplify the medical services and improve the efficiency; (2) to develop a healthcare system and service for the older patients; (3) to allow doctor to easily monitor the patients without meeting them and give comments on their blood glucose levels.

II. LITERATURE REVIEW

A. Diabetes

Diabetes is a disease with an abnormal blood glucose level in the bloodstream. Glucose is the simplest form of sugar. Blood glucose level is a standard to determine the concentration of the glucose inside the blood. As shown in table 1, usually for non-diabetic, the blood glucose level is between 4.0-5.9 mmol/L before meals and below 7.8 mmol/L at least 90 minutes after meals. For either Type 1 or Type 2 diabetics, the normal range of blood sugar is 4.0 – 7.0 mmol/L before meals and below 8.5 for Type 2 diabetic at least 90 minutes after meals and between 5.0 – 9.0 mmol/L for type 1 diabetics. For diabetics, when their blood sugar level is out of the range, they should consult with doctor. If the blood glucose level is too high, they should seek for medical attention immediately. Blood sugar level which is higher than 33.3 mmol/L can cause a condition called diabetic hyperosmolar syndrome. Diabetic hyperosmolar syndrome can lead to seizures, heart attack, stroke and coma (Mayo Foundation for Medical Education and Research).

On the other hand, Hyperglycaemia and Hypoglycaemia are two abnormal states of blood glucose level which can be known as high blood glucose level and low blood glucose level respectively. Normally, Hyperglycaemia and Hypoglycaemia happen due to pancreas does not function properly. Blood glucose level is controlled or regulated by 2 hormones: insulin and glucagon which are secreted by the endocrine pancreas (Norman, 2016).

Table 1. Normal range of blood sugar between different target types

Target Level by Type	Upon waking	Before meals (pre-prandial)	At least 90 minutes after meals (post prandial)
Non-diabetic	-	4.0 ~ 5.9 mmol/L	< 7.8 mmol/L
Type 2 diabetes	-	4.0 ~ 7.0 mmol/L	< 8.5 mmol/L
Type 1 diabetes	5.0 ~ 7.0 mmol/L	4.0 ~ 7.0 mmol/L	5.0 ~ 9.0 mmol/L
Children with Type 1 diabetes	4.0 ~ 7.0 mmol/L	4.0 ~ 7.0 mmol/L	5.0 ~ 9.0 mmol/L

B. Insulin

Insulin is a hormone produced by the organ named pancreas. Insulin is important for metabolism and utilization of energy from the ingested nutrients such as glucose (Mandal, 2019). Insulin acts as a 'key' that unlock the glucose channel to open up the cells in the body and allows the cells to take up the glucose and convert it into glycogen that can be stored in the liver and muscles and used as an energy source (Smith, 2018). Insulin allows the glucose in the bloodstream to go into and used by cells to prevent hyperglycaemia which can happen if excessive glucose is present in the bloodstream.

People with body that is insensitive to generate insulin is known as the Pre-diabetic. Lack of insulin will reduce the ability to use glucose as the energy source and the fat might become the energy source to be utilized. Breakdown of the fat cells will release ketone into the bloodstream. Excessive ketone in the bloodstream can lead to a serious condition known as ketoacidosis. Ketoacidosis can cause a lot of complications, such as severe dehydration, coma and brain swelling.

III. RELATED WORK

Nowadays, there are many countries that are progressively transforming into geriatric social orders due to the declining fertility rates and mortality rates. The health monitoring system with the technology of wireless sensor network, as proposed in this study can be widely used in environment, military, transportation, sports, medical and other fields (Al-Shaher & Al-Khafaji, 2017).

There are many studies conducted on blood glucose monitoring. These studies help to improve the monitoring of blood glucose in their respective way (Ling *et al.*, 2019). Shukla *et al.* (2016) designed a real-time continuous monitoring system to monitor the blood glucose level. PIC16 microcontroller, GSM SIM 900a and a glucose sensor were used in this project. The blood sample was taken, and biomedical signal was extracted by the blood glucose sensor. Then an amplifier was used to filter the signal. The microcontroller then received the signal and obtained the value of blood glucose level. The value was then sent to a personal computer and GSM module. The GSM module transmitted the data to specialist's mobile via SMS so that the doctor can monitor the patient's blood glucose level in real-time. The GSM module would automatically send the data to the doctor every time blood glucose testing is done, and every message consists of one-time data only. The limitation of this study is there is no graphical output for long term data analysis.

Naveen Kumar *et al.* (2013) proposed that an enzymatic nanosensor ws used to determine the blood glucose. The output of the nanosensor in the form of resistance was used as input to the circuit. The output of sensor was then amplified by the microcontroller circuit. After processing the data, the output was determined in the form of voltage. The relationship between glucose concentration, resistance of sensor and voltage of the project was then shown in graphs. After that, the LCD would display the result with the texts LOW, NORMAL and HIGH to represent the blood glucose level. The limitations of this study is, it does not display the actual value of the blood glucose level. If the patient's blood glucose level always touches the critical point, the patient would not know. Blood glucose level always touching the critical point might be due to insulin resistance. Prevention should be taken for those who have this symptom.

Wilkes *et al.* (2018) proposed a mechanical design of Spring-Loaded Lancet to be used to get the blood sample continuously. This eTac system can be divided into two parts: Disposable Cartridge and eTac Matrix. The Disposable Cartridge consists of test strip and spring-loaded lancet and was hidden in front of the shoe. The eTac Matrix consists of Li-ion batteries for power supply and microcontroller circuit to extract and send the data to smart phone. The eTac Matrix was hidden at the bottom of shoe. However, foot hygiene has to be practiced preventing infection.

IV. METHODOLOGY

A. Hardware

1. Glucose meter

Glucose meter is a medical device used to determine the approximate concentration of glucose in the blood. There are 2 types of glucose meter in the market: invasive glucose meter and non-invasive glucose meter. Invasive glucose meter is the traditional glucose meter usually found in the market. A strip is required to insert into the glucose meter to obtain the blood. A drop of blood is required to determine the blood glucose level. Non-invasive glucose meter is still a new product in the market. When compared to the invasive glucose meter, non-invasive glucose meter has higher price in the market, and no blood is required to determine the blood glucose level. Since no blood is required, one of the features of the non-invasive blood glucose meter is it can be used for continuous blood glucose monitoring. SINOCARE Medical Safe-Accu Blood Glucose Monitoring Solutions with export quality to medical stores in Germany, and Europe Countries have been used for this project. The specification of the devices as Table 2.

Table 2. Specification of SINOCARE Safe-Accu Blood Glucose Meter

FAD-GDH System
Blood sample: fresh capillary whole blood, venous whole blood
Calibration sample: venous plasma
Test range: 20-600mg/dL (1.1-33.3mmol/L)
Test time: 10s Blood volume:0.6μl
HCT: 30-60% Expired date:24 months
Memory: 200 test results with date and time
Battery: 2*AAA battery

2. Microcontroller

Arduino microcontroller is built on the open primitive simple I/O interface and has a Processing/Wiring development environment using a similar Java and C language. It contains two main parts. The hardware part is

the Arduino circuit board which is based on the ATmega328 microcontroller. It uses the 16MHz crystal oscilloscope to give a high frequency stability and has 14 digital input/output pins and 6 analog input pins which can be used to make circuit connection. The other is the Arduino IDE, the programming environment for the user to develop their own unique program and upload it to the Arduino board. Arduino can sense the environment through a variety of sensors, and feedback and influence the environment by controlling lights, motors, and other devices. The microcontroller on the board can be programmed through Arduino's programming language, compiled into binary files, and burned into the microcontroller. Programming for Arduino is done through the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing).

3. XBee

This study uses XBee to transmit and receive blood glucose data. Previous studies have highlighted the use of XBee to transmit large amount of data in medical services such as body temperature (Ling *et al.*, 2017). XBee S2C is the latest XBee module. XBee S1 module is simple to use, and no configuration is required to operate in peer to peer communication. The user can directly replace the wired serial connection with these devices. XBee S2 module is more complex to use when compared to XBee S1 module as configuration is required to work in peer to peer communication. When compared with the older version of XBee S1 and XBee S2 modules, XBee S2C module can reach longer transmission range either indoor or outdoor. Besides, XBee S2C also improves transmitter power output and receiver sensitivity with lower operating current. Table 3 shows the differences in features between the XBee modules. A pair of XBee S2C is used in this system.

Table 3. The differences in features between XBee modules

Parameters	XBee S1	XBee S2	XBee S2C
Indoor/Urban Range	up to 100 ft (30m)	up to 133 ft (40m)	up to ft (60m)
Outdoor, Line of Sight Range	up to 300 ft (100m)	up to 400 ft (120m)	up to 4000 ft (1200m)
Transmit Power Output	1mW (+0 dBm) Boost mode,1.25 mW (+1dBm Normal mode	2mW (+3 dBm) Boost mode,1.25 mW (+1dBm Normal mode	6.3mW (+8 dBm) Boost mode,3.1m W (+1dBm Normal mode
Receiver Sensitivity	-92 dBm Boost mode, -95 dBm Normal mode	-96 dBm Boost mode, -95 dBm Normal mode	-102 dBm Boost mode, -100 dBm Normal mode
Operating Current (Transmit)	45mA (3.3V) Boost mode, 35mA (3.3V) Normal mode	40mA (3.3V) Boost mode, 35mA (3.3V) Normal mode	45mA (3.3V) Boost mode, 33mA (3.3V) Normal mode
Operating Current (Receive) SPI	50mA (3.3V) Boost mode, 38mA (3.3V) Normal mode	40mA (3.3V) Boost mode, 38mA (3.3V) Normal mode	31mA (3.3V) Boost mode, 28mA (3.3V) Normal mode
SPI	Not Supported	Not Supported	5Mbps maximum (burst)
Number of End Devices	12	12	20+

B. Software

XAMPP is a free and open source cross-platform web server solution stack package developed by Apache Friends which includes complete pack of Apache, MySQL, FileZilla, Mercury and Tomcat. Simple and lightweight Apache distribution makes XAMPP extremely easy for developers to create a local web server for testing and deployment purposes. In this study, the XAMPP is used to develop a local network for data uploading and downloading through the network between the devices.

MySQL is the most popular open source database. It is one kind of Relational Database Management System (RDBMS) in which the data and its relationships are stored in the form of tables that can be accessed by the use of MySQL queries in almost any format that the user wants. MySQL is a database system used on the web server and it is ideal for

both small and large application. It is very fast, reliable and easy to use. PHP is a server-side scripting language designed for web development but can also be used as a general-purpose programming language. PHP is also a server-side programming language which can be used to produce dynamic web pages.

C. I2C protocol

I2C protocol is built with 2 lines. There are Serial Clock Line (SCL) and Serial Data Line (SDA). In I2C protocol, the data transfer between the devices (masters and slaves) is synchronized by the clock signal transfer in SCL line which is generated by the master device. With the notice from SCL line, SDA line starts to transfer and receive the data. All devices connected in I2C bus have unique 7-bit addresses to identify each other. The data is transmitted in 8-bit data byte. The communication starts with the start bit. The start bit acts as the signal to give attention to all the connected devices. Then the address signal of the device is sent by the master device along with the indication of Read and Write operations. The data signal comes after indication signal and ends with the end signal. There are 3 modes with different data transfer rates to be chosen, which are standard mode with 100 kb/s, fast mode with 400 kb/s and high-speed mode with 3.4 Mb/s.

Table 4. Comparisons between I2C, UART and SPI

Features	UART	SPI	I2C
Pin Designation	TxD: Transmit Data RxD: Receive Data	SCLK: Serial Clock MOSI: Master Output, Slave Input MISO: Master Input, Slave Output SS: Slave Select	SDA: Serial Data SCL: Serial Clock
Data Rate	230 ~ 460 kbps	10 ~ 20 Mbps	Standard mode: 100 kbps Fast mode: 400 kbps High speed mode: 3.4 mbps
Distance	Low	High	Medium
Communication Type	Asynchronous	Synchronous	Synchronous
Number of masters	Not Application	One	One or more than one
Clock	Device use independent clock	One common serial clock	One common serial clock
Protocol	8-bit data	Depend on manufacturer	ACK bit of 8 bits data

By comparing the different types of data transfer protocols as shown in Table 4, SPI and I2C are more stable in data transfer by using a synchronous clock signal when compared to independent clock signal of UART. I2C protocol uses 2 data lines as data transfer lines in which less data line is used in data transfer when compared to 4 data lines used in SPI protocol. From this perspective, I2C is significantly superior to SPI in sparing pin, board routing and thus building an I2C network is easier (Leens, 2009).

D. System block diagram

From the block diagram as shown in Figure 1, there are two types of arrows. The one-way arrow means the data transfer is in one way. Two-way arrow on the other hand means there is a communication between the two devices. The blood glucose sample data is first obtained by the blood glucose meter. Then, microcontroller is used to read or catch the data from the blood glucose meter. The blood glucose data is then transferred into the software via COM port in wireless connection. A pair of XBee modules are used as a transmitter and a receiver to achieve data transfer in wireless transmission. The data is then uploaded to internet and stored into MySQL database in the server. All the data of the user is stored in the server. With this feature, the user can manage their data everywhere. The purpose of this system to use a network storage is to be able to obtain big amount of data for analysis.

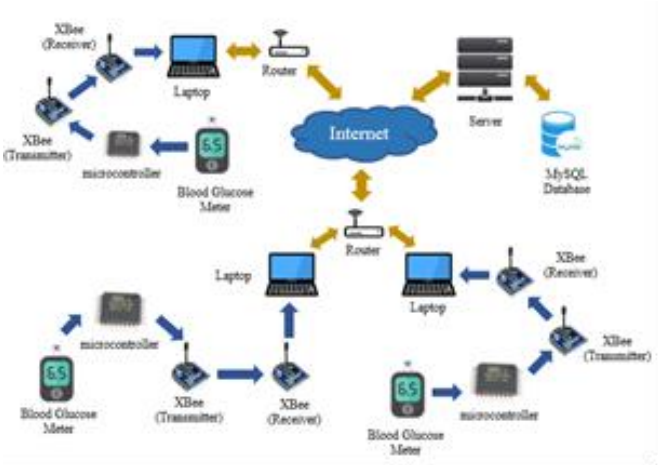

Figure 1. Block diagram of the system

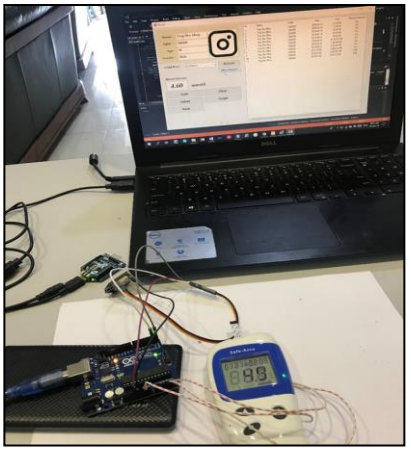

Figure 2. System setup and data transmit wirelessly through XBee S2C

V. RESULT

A. Catch and decode the analog signal from the blood glucose meter

This study uses analog read function of ATmega328P microcontroller chip to read the analog signal. However, the ATmega328P microcontroller will not directly show the voltage measured. Instead, the microcontroller will show the voltage in numbers between 0-1024 which represent 0-5 V in voltage form as shown in the following formula:

$$Y = \frac{x}{1024} \times 5 \quad (1)$$

where Y = result in voltage form, x = input value

The formula is used to convert the input data from number form into voltage form. There are four factors that might affect the result of blood glucose meter. There are strips factor, physical factor, patient factor and pharmacologic factor (Ginsberg, 2009).

In strips factor, small amount of strip-to-strip variation will cause the inaccuracy in blood glucose reading. Besides, the reduction of the mediator can cause problems with the accuracy of electrochemical blood glucose strips. In physical factor, the most common influencers are altitude and temperature. Glucose oxidase biosensor strips are often sensitive to oxygen concentration. The mediator and oxygen can both compete to take electrons from the reduced form of the glucose oxidase enzyme. These 2 factors are the most common factors that cause the different signals being generated by the op-amp with the same reading.

B. Software application

Server status will be displayed after the software is logged in. The status will show “Connected” if there is a connection between the server and the computer. Otherwise, it will show “Disconnected” if the connection between server and client’ computer is fail. XAMPP can be easily used to open the port for the use of the Apache server and MySQL database. If the MySQL database is in OFF state, no connection is established because it is not the assigned port to be used with the database.

Figure 3. First page

When it is ready to communicate with the server, the patients can login into their own account to manage and view the account. The user needs to register an account for the first-time login and the user information will be stored into the database.

The blood glucose data is then transferred from the blood glucose monitoring device into the software via COM port in wirelessly. All the data is saved and stored into the database. All the records are shown in table form and the users can easily manage their blood glucose record by either adding a

new one or deleting the unwanted data. After registering for the first time, the patient can choose a registered doctor as their exclusive doctor. In this system, the doctors can login into their account to view their patients' information and give some comments on the patients' health status regarding the blood glucose. A patient's profile picture is attached for doctor to recognize who the patient is.

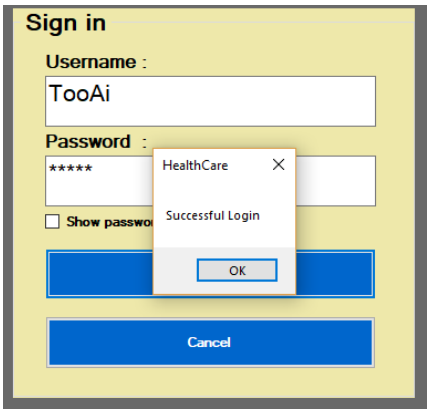

Figure 4. Login page

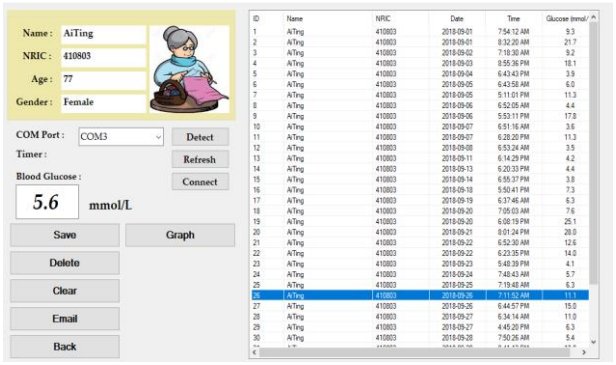

Figure 5. Data management

C. Data analysis in graphical way

Figure 5 shows the historical view of the blood glucose data of a user. With the software developed, the user can upload and store their blood glucose information. The user can see a trend of their blood glucose levels by searching the history. The result in Figure 6 shows that the user has floating blood glucose levels in September 2018.

From the point graph as shown in Figure 6, glucose data located at zone 1: yellow zone means the blood glucose is below 4 mmol/L and is considered low in blood glucose. Glucose data located within zone 2: green zone means the blood glucose is within the normal range of 4.1- 7.0 mmol/L for type2 diabetic. Zone 3: orange zone is a warning zone. For those whose blood glucose data are mostly located within this zone, the patients need to take care of their blood glucose level. If most of the data is located within this zone, this means their glucose tolerance has been damaged. For those glucose data located within zone 4: red zone, this means the blood glucose level is too high. For the blood glucose level above the red zone, the patients need to seek assistance from doctor immediately. The distribution of the blood glucose level has a clear view within the point graph. Furthermore, from the point graph as shown in Figure 7, there are 1/3 of the glucose sample that are located within the red zone, indicating that the patient might eat too much, does not have enough exercise, or does not have enough insulin injection.

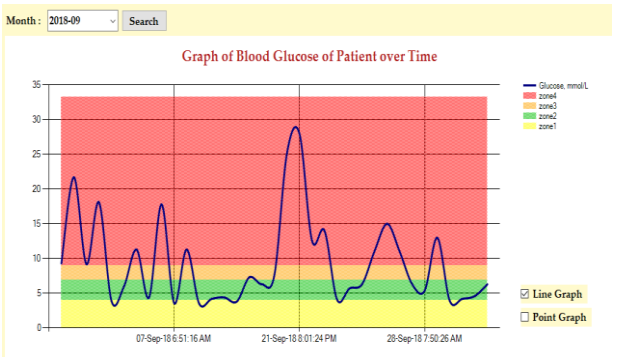

Figure 6. Historical view of the blood glucose data

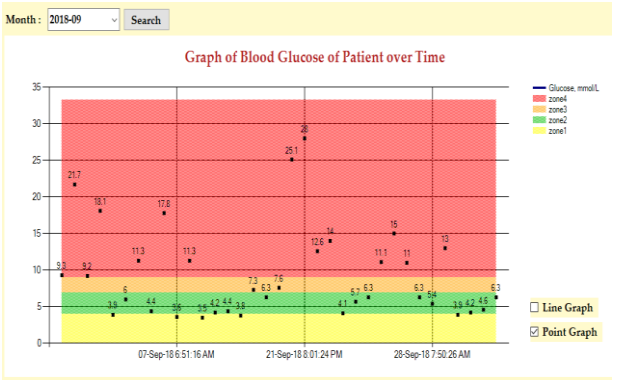

Figure 7. Patient's blood glucose data in point graph

D. Sampling distribution of blood glucose level of a diabetic over 9 months

Among the patients, one of the female diabetic patient ages 77 have being chosen for presenting the detail data in blood glucose over the January until September 2018. Figure 8 shows sampling distribution of the blood glucose samples collected from a diabetic over 9 months. From the figure, the median value of the samples collected is 9.4 mmol/L, the

first quartile, Q1 is 6 mmol/L, the third quartile, Q3 is 15 mmol/L, the upper extreme is 28.4 mmol/L and the lower extreme is 3.5 mmol/L. There are 2 outlier values, 32.7 mmol/L and 30.4 mmol/L. These 2 outlier values show that the diabetic has the risk to fall into the condition called as diabetic hyperosmolar syndrome. As the sampling distribution shows, the interquartile range is between 6 mmol/L and 15 mmol/L, which means that 50% of the samples are within this range. This means that for most of the time, the diabetic's blood glucose levels fall within this range. The difference between first quartile and third quartile is 9 mmol/L, which is considered as non-concentration sample data for blood glucose.

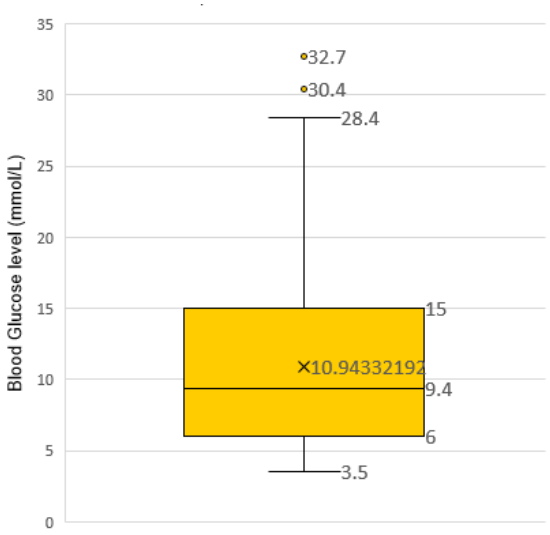

Figure 8. Sampling distribution of blood glucose samples of a diabetic over 9 months

Besides, the range between median and the Q3 is higher than the range between median and Q1. Furthermore, the samples collected show that the diabetic has an average blood glucose level of 10.94 mmol/L, which is higher than the median. This indicates that the distribution of blood glucose samples collected in this study concentrates more in higher values. In this study, the blood glucose level of the diabetic often is higher than the median, which is 9.4 mmol/L. According to Table 1, for Type 2 diabetes, the normal blood glucose level before meal should be in between 4.0-7.0 mmol/L and should not be higher than 8.5 mmol/L after meal. Therefore, the blood glucose level of the diabetic in this study is out of the recommended range most of the time.

E. Statistical analysis of the mean blood glucose levels of a diabetic over 9 months

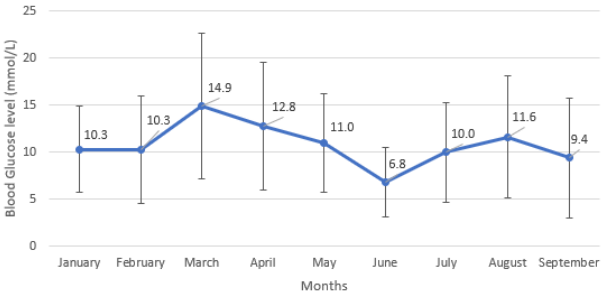

Figure 9. Mean blood glucose levels of a diabetic over 9 months

The graph shown in Figure 9 is statistical analysis of the blood glucose sample data obtained from a diabetic over 9 months. The mean value of the blood glucose levels for each month is different and the standard deviation of sample data obtained each month is also different. From the graph, the mean blood glucose levels for both January and February is 10.3 mmol/L and it goes up to 14.9 mmol/L in March. After that, the mean blood glucose levels go down for 3 consecutive months and reaches the lowest value at 6.8 mmol/L in June. The mean value then goes up and down again for the next 3 months. The up and down lines in the graph show that the diabetic does not have a stable blood glucose level. Furthermore, the standard deviation in June is the lowest, which means that the blood glucose level in this month is more consistent when compared to other months. It further indicates that in that particular month, the blood glucose levels of the diabetic are under control. The higher value the standard deviation, the larger is the range between the maximum and minimum value. Therefore, high standard deviation value shown in a particular month indicates that the blood glucose levels of the diabetic in that month keep floating and are not consistent.

VI. CONCLUSION

A long-term monitoring of the blood glucose levels for a diabetic and non-diabetic are important. For non-diabetic, one can take action earlier to prevent in getting type-2 diabetes. For diabetic, the amount of the insulin to be injected into the patient can be adjusted based on the blood glucose sample data. Furthermore, long-term monitoring of

the blood glucose levels also reflects the lifestyle of the patient. For further improvement, the researchers would like to suggest that a real-time blood glucose monitoring system with an embedded insulin injection device to be constructed to monitor the real-time blood glucose levels. When the blood glucose level is higher than normal, the embedded insulin injection device will inject the necessary amount of insulin based on the real-time blood glucose levels. With this device, the diabetic can maintain their blood glucose levels within the recommended normal range.

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