IOT Based Non-Invasive Glucose Monitoring System for Diabetic Patient

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Abstract
The development of technology is very rapid at present, especially in the field of medical engineering. This paper focuses on an insole that can check the glucose level of a person by putting their feet on the insoles. It provides information about gait mechanics and has a wide range of applications, in clinical situations. In this project the sensors are used to gain insight about infrared, skin sensor of diabetic person. It is also wearable real-time monitoring and feedback faces the challenge of patient adherence. The insole consists of an array of sensors. The pressure-sensing smart insole system provided unique feedback to both patient and provider in ways that contributed to the prevention of pressure as well as highlight the importance of prescribed a non-invasive method. Real-time visualization of pressure mapping which are using internet data is also incorporated because it makes it much easier to understand the data needed.

Keywords: Diabetic, glucose, non-invasive

1.0 Introduction

Diabetes is a disease that occurs when the blood glucose, also called blood sugar, is too high. Blood glucose is the main source of energy and comes from the food eaten by human. Insulin, a hormone made by the pancreas, helps glucose from food get into the cells to be used for energy. Some 3.6 million Malaysians are suffering from diabetes, the highest rate of incidence in Asia and one of the highest in the world, said Health Minister, Datuk Seri Dr. Dzulkefly Ahmad (Dzulkefly Ahmad, 2019). Seven million Malaysian adults are likely to have diabetes by 2025, a worrying trend that will see diabetes prevalence of 31.3% for adults aged 18 years and above, he added. This exponential increase is significantly within type two diabetes, which is largely the result of excess body weight and physical inactivity. The government is giving serious attention to this increase as it is becoming a major economic burden on the healthcare system and national economy. Dr. Dzulkefly said although Malaysia has a parallel public and private system, the majority of treatment for chronic diseases is provided by the public health system heavily subsidized by the government at a "significant cost". A macroeconomic study in 2011 showed the cost at about RM2bil, representing 13% of the healthcare budget for the year 2011. The analysis reflects that this cost could be as high as RM3.52bil if societal costs were included. The one-day event held at Sunway Medical Centre brought specialists to discuss the latest developments in acute and general medicine.

The hardware used are infrared sensors, skin sensors as an assistant to the infrared data so that the program can match the data of the infrared and the skin sensors. It also using Arduino MK1000, Light Emitting Diode (LED) and buzzer to help detect the glucose level needed. Based on our observations and research about the relationship between the infrared and the glucose level, when the infrared is between range of 70 – 80 bpm, the skin sensor are needed to sense the heat of the person's feet as if the range of data of the person heart rate is equal to the heat of a normal person whom does not having diabetes, the data of the glucose level will appear at the phone or apps used by using internet (wifi). This is because the heat of the skin whom having diabetes is more heater than the normal person usual range. As the heart rate will be put on the feet to sense the heat and the heart rate as it physically a little far from the person heart itself. So, using skin sensor to help the heart rate data that combine to easy the program to produce a good result and exact data that we want for the person.

By using Wi-Fi, the application that used are Thingspeak for appearing the result or data of whether the person that are being examine is having diabetes or not with the relationship between the infrared data and the heat of the skin. Thingspeak is an Internet of Thing (IoT) platform that are collected data that sense at the same time and show it on the phone or PC used. By connecting to the internet, by just need to log in the account on the link and inserting the personal information and sense the feet, automatically the data will appear with the analysis needed. At the insole, buzzer and LED with difference color which are white and green is put to react with the glucose level shown. The buzzer will sound beeping when the results or the data of the glucose level for the person is high. The green LED will on if the glucose level is normal whereas the white LED will on if the glucose level is low.

2.0 Literature Review

Pressure measurement is already used in a variety of situations. It provides information about gait mechanics and has a wide range of applications example as in clinical situations. In this project the sensors are used to gain insight about glucose level. Real-time visualization of pressure mapping is also incorporated because it makes it much easier to understand the data. Pressure measurement is already used in a variety of situations. It provides information about gait mechanics and has a wide range of applications example as in clinical situations especially for diabetic patients. In this project the sensors are used to gain insight about infrared distribution. Real-time visualization of pressure mapping is also incorporated because it makes it much easier to understand the data.

The measurement of infrared and skin sensors is an important technique used by medical personnel for diagnosing and treating a wide range of non-communicable diseases and conditions. By measuring and especially monitoring a patient's infrared, medical personnel can be alerted to the related health condition at an early stage, increasing the likelihood of successful treatment. While indirect methods of skin sensor monitoring, such as with a pressure skin's sensor and infrared sensor, are often desired for quick pressure readings, these methods can be inaccurate by as much as 10 percent, making them undesirable for longer term blood pressure monitoring of more critical patients. Consequently, direct blood pressure monitoring methods are preferred for patients with serious or critical conditions due to their improved accuracy and easier long-term implementation. B. Paul et al. (2012) had developed and implemented a non invasive glucose meter, in which all the measurements were carried out in vivo to measure the glucose level by using sensor on the hand without needed to prick the patient's finger to obtain the blood.

Moreover, T. N. Gia et al. (2017) have designed an IOT-based system architecture from a sensor device to a back-end system for presenting real-time glucose, body temperature and contextual data (i.e. environmental temperature) in graphical and human-readable forms to end-users such as patients and doctors. This method investigate energy consumption of the sensor device and design energy harvesting units for the device. The work provides many advanced services at a gateway level such as a push notification service for notifying patient and doctors in case of abnormal situations (i.e. too low or too high glucose level). The results show that the system is able to achieve continuous glucose monitoring remotely in real-time. In addition, the results reveal that a high level of energy efficiency can be achieved by applying the customized IF component, the power management unit and the energy harvesting unit altogether in the sensor device., K. Aziz et al. (2016) had system puts forward a smart patient health tracking application that uses sensors and microcontroller to track patient health and provides precautionary messages to the patient's mobile phone. In application system uses cholesterol level as well as blood glucose level to keep track of patient health. If system detects any abrupt changes in the patient's cholesterol or blood glucose level, the system automatically alerts the user about the patient's status from the server in the hospital. P. Gope et al. (2016) assessment is carried out by monitoring the patient's body sensor values (ECG, BP and blood glucose) in a web based link using IOT (Internet of Things).

S. B. Baker et al. (2017) designed an Internet of Things remains a relatively new field of research, and its potential use for healthcare is an area still in its infancy. In their article, the Internet of Things is explored and its suitability for healthcare is highlighted. Several pio-neering works towards developing healthcare IoT systems are discussed. Building on the recurring themes from these works, a generic and standardized model for future end-to-end IoT healthcare systems is proposed, with the aim of guiding the future development of such systems. Internet of Things (IoT) technology has attracted much attention in recent years for its potential to alleviate the strain on healthcare systems caused by an aging population and a rise in chronic illness. Standardization is a key issue limiting progress in this area, and thus this paper proposes a standard model for application in future IoT healthcare systems. This survey paper then presents the state-of-the-art research relating to each area of the model, evaluating their strengths, weaknesses, and overall suitability for a wearable IoT healthcare system. Challenges that healthcare IoT faces including security, privacy, wearability and low-power operation are presented, and recommendations are made for future research directions.

According to R.S.H. Istepanian et al. (2011), an amalgamated concept of Internet of m-health Things (m-IoT) has been introduced recently and defined as a new concept that matches the functionalities of m-health and IoT for a new and innovative future (4G health) applications. It is well know that diabetes is a major chronic disease problem worldwide with major economic and social impact. To-date there have not been any studies that address the potential of m-IoT for non-invasive glucose level sensing with advanced opto-physiological assessment technique and diabetes management. In this paper we address the potential benefits of using m-IoT in non-invasive glucose level sensing and the potential m-IoT based architecture for diabetes management. We expect to achieve intelligent identification and management in a heterogeneous connectivity environment from the mobile healthcare perspective. Furthermore this technology will enable new communication connectivity routes between mobile patients and care services through innovative IP based networking architectures.

K.A.U. Menon et al. (2013) propose a non-invasive blood glucose monitoring system using near-infrared (NIR). Glucose in blood is predicted based on the analysis of the variation in the received signal intensity obtained from a NIR sensor. The predicted glucose data is sent wirelessly to a remote computer for visualization. Recently, some IoT-based applications for glucose monitoring have been built. However, those systems do not attentively consider energy efficiency of sensor nodes and the communication between sensor devices and a gateway. C. Shih-Hao et al. (2016) work proposes the system which offers convenience and lower the risk of erroneous measurement. In the basic rule service, the patient's standard blood-glucose range is divided into different diabetic types (such as Type 1 or Type 2) and measurement scenarios to produce seven grades of blood-glucose measurements (low 3, low 2, low 1, normal, high 1, high 2, and high 3). Because the entire blood-glucose monitoring measurement range is between 20 milligrams per deciliter and 600 mg/dl; the abnormality in either case can be critical. Because each patient's health condition is unique, the system allows patients to set their own grade ranges based on their doctor's suggestions, with the exception of low 3 and high 3. Blood-glucose grades will be applied to the anomaly detection rules to determine levels of abnormality.

A. A. Majid et al. (2015) work proposes self-management of diabetes enables real-time clinical interaction and feedback tailored to the personal needs of the patient, utilizing current and historical patient data. The physical layer nodes are linked to a web based application layer through an existing telecommunication infrastructure. It interfaces the various objects of the physical layer to other objects. The application modules, which handle all users' related functionality, are designed to be compliant with the Model-View-Control (MVC) pattern. Based on the collected reading, the mobile phone provides the necessary feedback and support in calculating the required insulin bolus. The drawback of this paper is lower efficiency and low manageable capability to cover over distance. Non-invasive commercial monitors are still in development, such as the SugarBEAT by Nemaura Medical Inc. UK that performs the glucose measurement using a disposable skin-patch connected to its own transmitter. A. Antonio et al. (2019) has highlight an equipment from MediWise Ltd. United Kingdom which introduced the GlucoWise, which works by transmitting low power radio waves through the earlobe. In addition, D. H. Keum et al. (2020) has introduces a wireless smart contact lens for diabetic diagnosis and therapy which uses the tear fluid for measuring the glucose concentration.

3.0 System Development

Proposed device consists of two main parts which are hardware and software. Hardware includes insoles, pressure sensor (infrared), microcontroller (Arduino Uno), while software includes coding process to Wi-Fi and smartphone. Figure 1 shows the block diagram of the proposed system being updated.

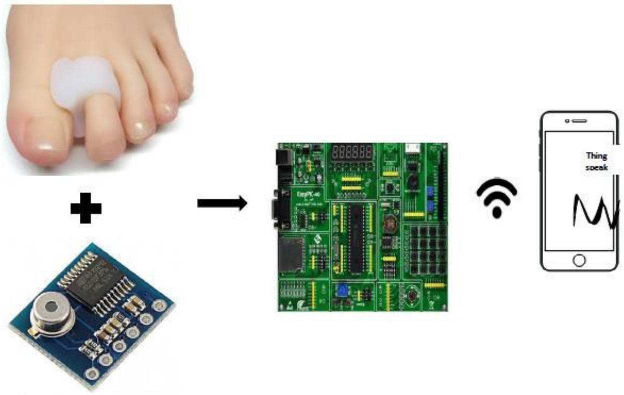
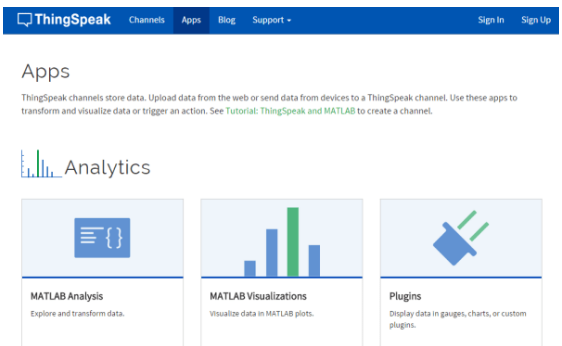


Figure 1: Block diagram of proposed system

The digitized signal from microcontroller is sent to the smart phone through internet for simplicity of the system. The application software is designed in interactive manner using Thinkspeak App Inventor by connecting it using Wi-Fi. Patients could view and save their measurement data through android phone. Furthermore, the data could be sent to their personal doctor or caregivers for further action. The application software and prototype of the developed system is shown in figure 2 (a) and figure 2(b).



(a) Application software using Thinkspeak application.

(b) The prototype of the insoles.

Figure 2: Illustration of the application software and the prototype of the developed system

Figure 3 is the flowchart of the process to use this developed system. The process included from the start it as for the patient information until the results appear. Following the process that is summarize by using the flowchart shown in Figure 3, first, it will ask for the patient's information such as name, age and BMI. Next, the patient will put their feet and toe on the insole. After that, the coding will proceed with the calculating and measuring their data as finally the results of the diabetic level appear at the apps that are being used. As for the results, the data appear will also appear at the prototype by lighting the LED which represents difference meaning.

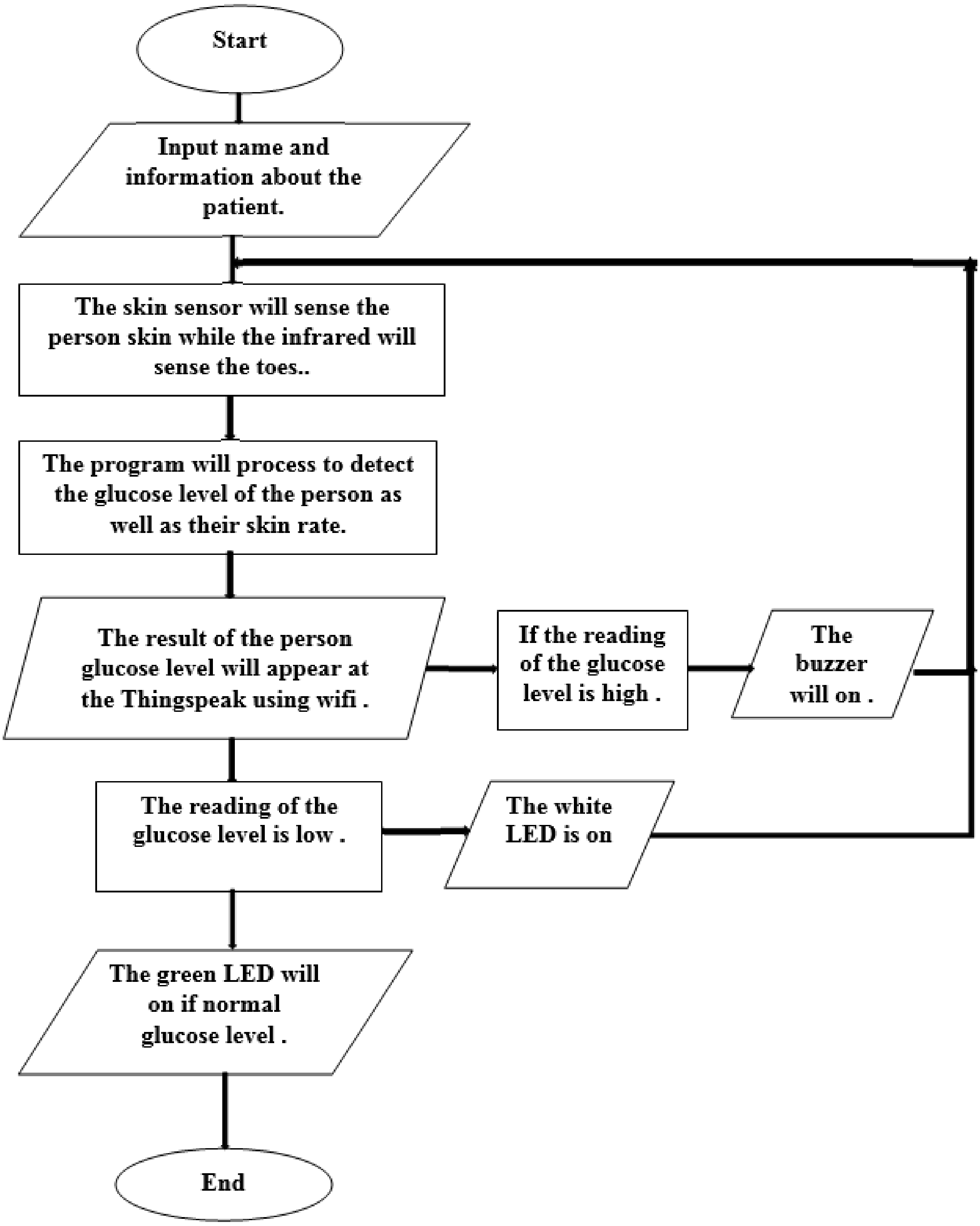


Figure 3: The flowchart of the process involves in the developed system.

The pressure sensor of the prototype has been verified using infrared sensor at calibration laboratory to meets with the requirement standard of pulse rate measurement with skin heat sensor as an assistant. Electrical safety test have being carried out to ensure the machine prototype is applicable to use. Table 1 depicts the partial results of the normal glucose levels for both men and women according to standard measurement from WHO. Moreover, Figure 4 also is the kit used to compare the invasive kit and non-invasive system used for this developed system process accurately. Based on this Table 1 and Figure 5, the information about the normal glucose level for the both men and women is use for and compare together as the data used for this developed system to process more result accurately.

Table 1: Glucose level generally for men and women

Risk level	**Average Blood Sugar**	
	(mmol/L)	**(mg/dL)**
optimal	4.6	83
excellent	<5.4	<97
good	<6.0	<108
danger	>7.8	>140

Figure 4: The display results of the invasive kit used for checking diabetic level.

4.0 Results and Discussions

The developed prototype system has been tested to evaluate the pressure sensors capability at an insole when the feet is fitted. The results has been compared with previous related research for insole pressure measurement as stated in Table 2. Each experiment has been run a number of times to confirm the repeatability of the system.

Table 2: The data obtained from previous research

Summary of regression analysis			
Number of subjects	Number of tests	Slope mmol/L	Intercept mmol/L
100	600	0.959	-0.044

Based on the observation from F. Lin et al. (2016), a wearable sensor device for unobtrusive gait monitoring in daily life, a novel sensor device smart insole is to tackle the challenge of efficient gait monitoring in real life. An array of electronic textile (e-Textile) based pressure sensors are integrated in the insole to fully measure the plantar pressure. Smart Insole is also equipped with a low-cost inertial measurement unit including a 3-axis accelerometer, a 3-axis gyroscope and a 3-axis magnetometer to capture the gait characteristics in motion. Smart Insole can offer precise acquisition of gait information. Meanwhile, it is lightweight, thin and comfortable to wear, providing an unobtrusive way to perform the gait monitoring. Furthermore, a smartphone graphic user interface is developed by M. Tan et al. (2015) to display the sensor data in real-time via Bluetooth low energy. They perform a set of experiments in four real-life scenes including hallway walking, ascending or descending stairs and slope walking, where gait parameters and features are extracted. Finally, the limitation and improvement, wearable and usability, further work and healthcare-related potential applications are discussed. Tests were done prior to each components involved to ensure its functionality for both hardware and software. The verification and calibration of the selected component are discussed. The diabetic measurement results obtained from the proposed system. Figure 5 shows the prototype for the developed system and its results appear for a normal diabetic range on the prototype. As in Figure 5(a) is the picture of the prototype that had been developed fully with the system and ready for testing and use to obtain needed data. Figure 5(b) is the picture that shows the result on the prototype which the LED green will light up when the normal ranges for the diabetic level is appear on the apps as calculated and tested.

(a) The prototype of the system. (b) The results appear at the prototype.

Figure 5: The prototype of the developed system and its results for normal glucose level

Figure 6 shows the home screen and the example data of glucose level shown which usually appear when the patient using the application after being ask their information. This will easy the patient to send or save their results data for the future or for further measurement with their own specialist doctor.

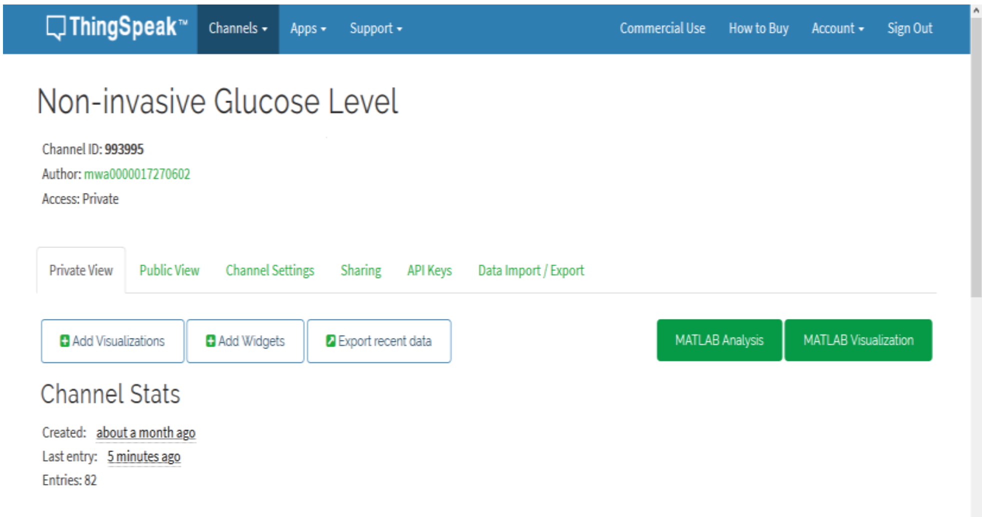


Figure 6: The home screen for the application used for the glucose level appears.

Figure 7, 8 and 9 shows the examples of the print screen for the Thingspeak analysis on MATLAB that is obtain by using the data from the tested glucose level taken. Based on Figure 7 and 8, the MATLAB code was entered and run to see the output result analysis as illustrated in Figure 9.

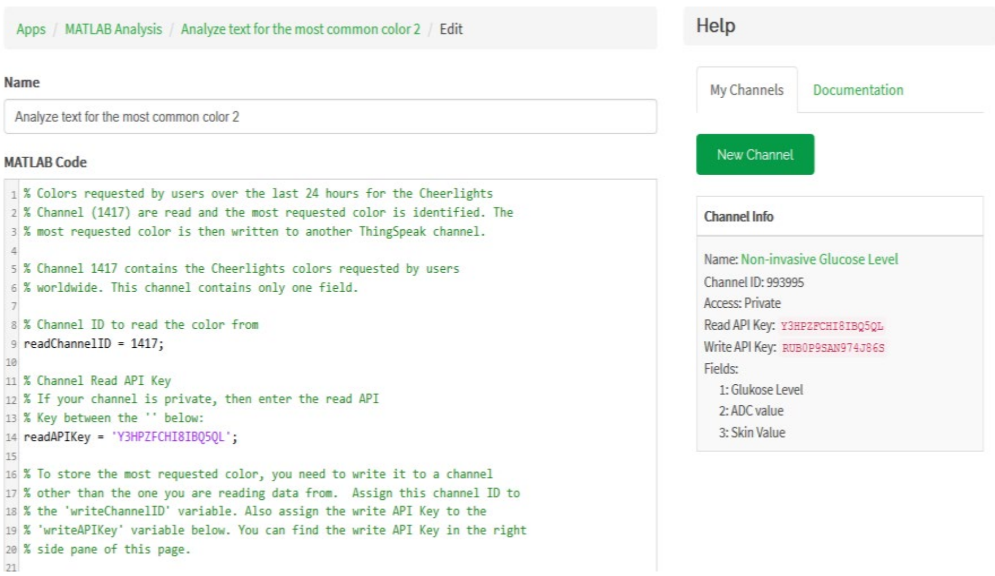


Figure 7: The MATLAB code entered to gain the output for the MATLAB analyis.

```
% TODO - Replace the [] with channel ID to write data to:
writeChannelID = [993995];
% TODO - Enter the Write API Key between the '' below:
writeAPIKey = 'RUB0P9SAN974J86S';

% Read colors specified during the last 24 hours. Learn more about the
% THINGSPEAKREAD function by going to the Documentation tab on the right
% side pane of this page.
colors = thingSpeakRead(readChannelID, 'numDays', 1, 'outputFormat', 'table', 'ReadKey', readAI

% Convert the color strings to categorical data type
colors24hrs = categorical(colors.LastCheerLightsCommand);

% Partition and bin the colors in the dataset into a distribution corresponding to each color
[counts, centers] = histcounts(colors24hrs);

% Find the color with the maximum number of counts
[maxCounts, maxCountIndx] = max(counts);

% Find the color that was mentioned the most
maxRequestColor = centers(maxCountIndx);

% Convert categorical type to string
maxRequestColor = char(maxRequestColor);

display(maxRequestColor, 'The most requested color over the last 24 hours');

display(['Note: To successfully write data to another channel, ',...
    'assign the write channel ID and API Key to ''writeChannelID'' and ',...
    '''writeAPIKey'' variables above. Also uncomment the line of code ',...
```

Figure 8: The MATLAB code entered.

```
display(['Note: To successfully write data to another channel, ',...
    'assign the write channel ID and API Key to ''writeChannelID'' and ',...
    '''writeAPIKey'' variables above. Also uncomment the line of code ',...
    'containing ''thingSpeakWrite'' (remove ''%'' sign at the beginning of the line.)'])

% Learn more about the THINGSPEAKWRITE function by going to the Documentation tab on
% the right side pane of this page.

% thingSpeakWrite(writeChannelID, {maxRequestColor}, 'WriteKey', writeAPIKey);
```

Save and Run | Save*

Output

```
The most requested color over the last 24 hours =

    'yellow'

Note: To successfully write data to another channel, assign the write chann
```

Figure 9: The output result obtained from the coding entered.

Figure 10 shows one of the MATLAB visualization obtained from the data that entered and taken to take and calculated the glucose level by using the developed system together. Figure 10 and 11 shows the MATLAB code is enter before obtaining the MATLAB visualization output at the end. As in Figure 12 and Figure 13, the picture shows the output result data obtained after run the MATLAB code.

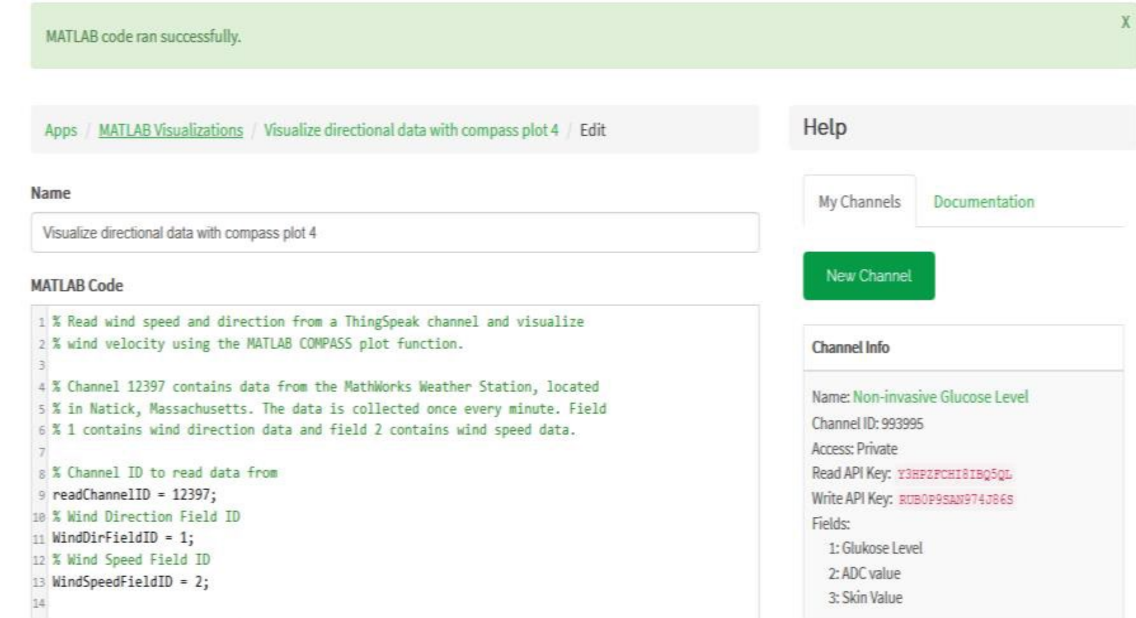


Figure 10: The MATLAB code entered to obtained the output.

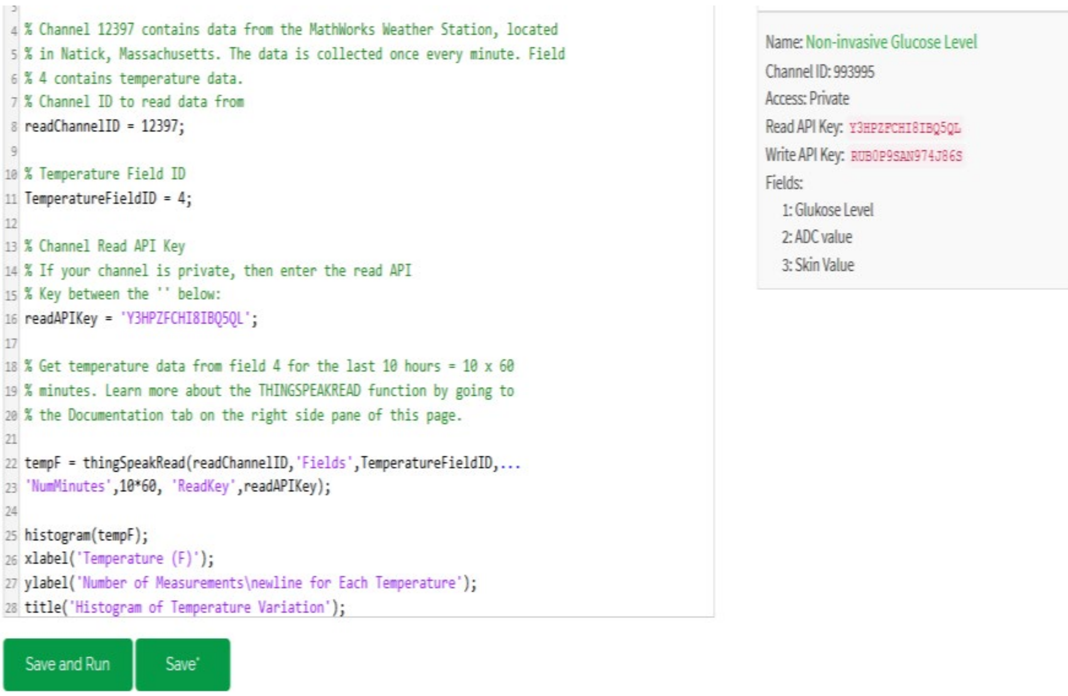


Figure 11: The continue from the MATLAB code that are entered.

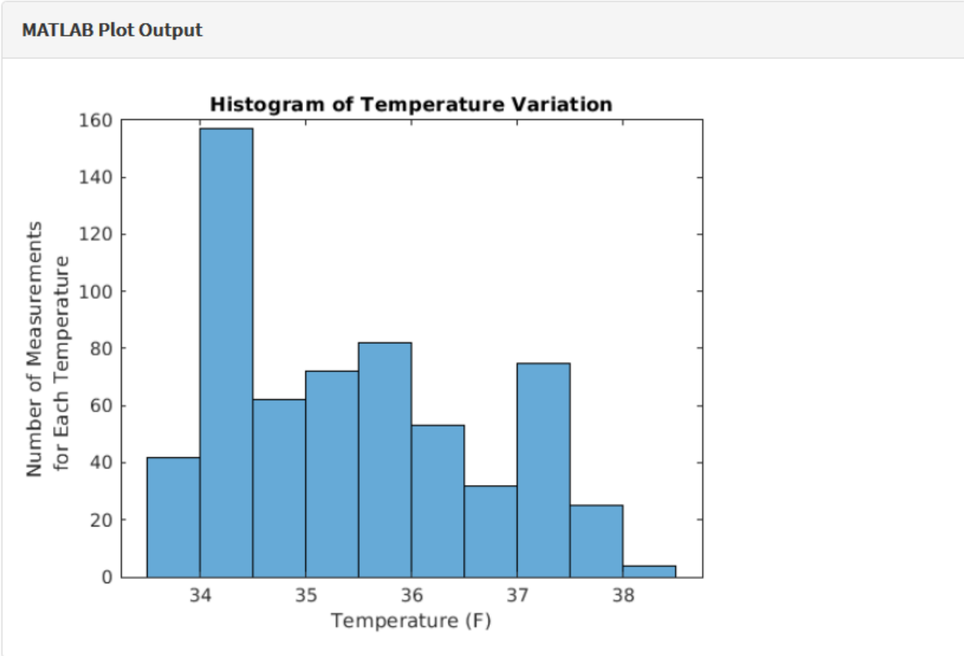


Figure 12: The output result obtained after run the MATLAB code.

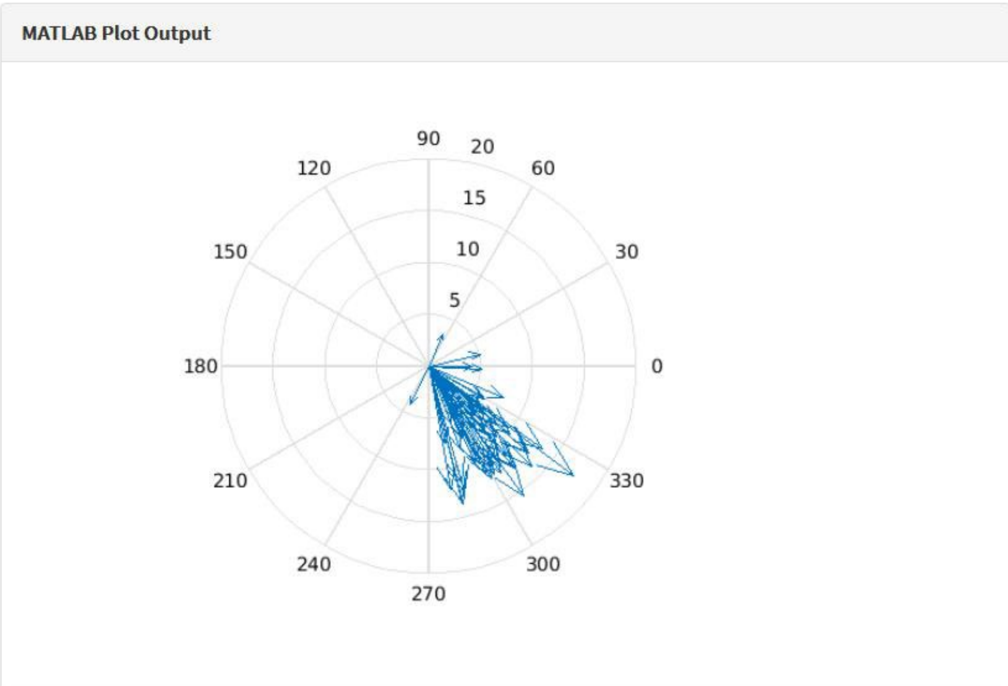


Figure 13: The other data output plotted from the data taken using the developed system.

Table 3 show the result data appear when measuring the glucose level by using the developed system with different type of people. As in Figure 14 shows the data that will appear at the screen of the apps used for the developed system connected together by using IoT.

Table 3: The data obtained from developed system

Glucose level	Skin data
95	184
86	175
72	161
55	144

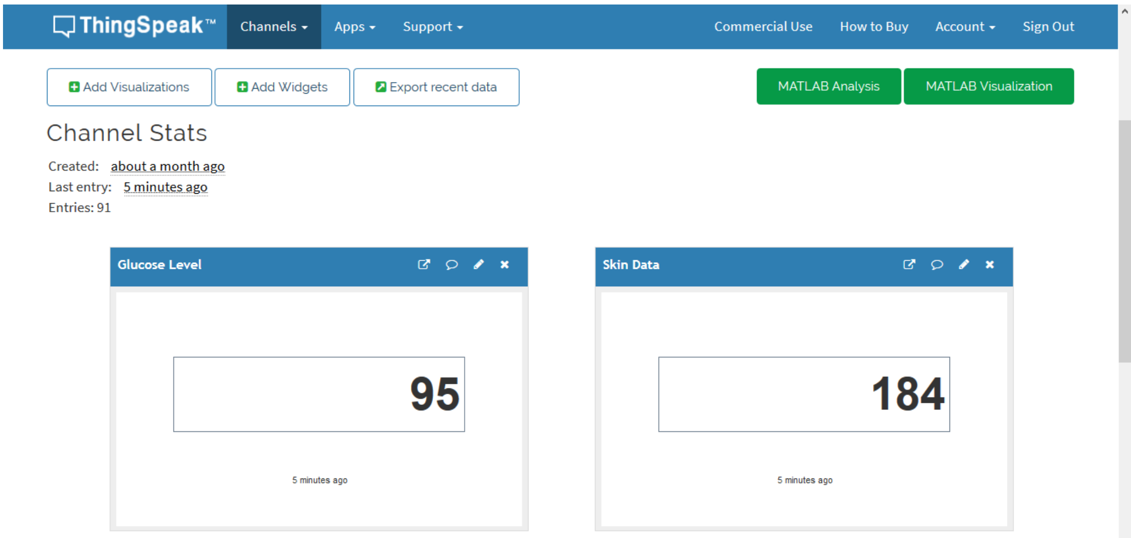


Figure 14: The data comes out on the screen.

Table 4 is the comparison that are obtained when comparing the developed system which are non-invasive and other system which are invasive for an accurate results for the results obtain in this developed system which also can give stable and trustworthy for the users.

Table 4: Comparison between laboratory and self techniques

Characteristics	Laboratory	Self-monitoring
Accuracy	Very good	Good
Sensitivity	Very good	Good
Measurement time	Long	Quick
Trained laboratory personnel	Yes	No
Sample type	Blood, serum, plasma, urine	Infrared sensor
Blood extraction method	Invasive	Non-invasive

Figure 15 shows the picture of the comparison between the data that measured using two different method which are invasive and non-invasive.

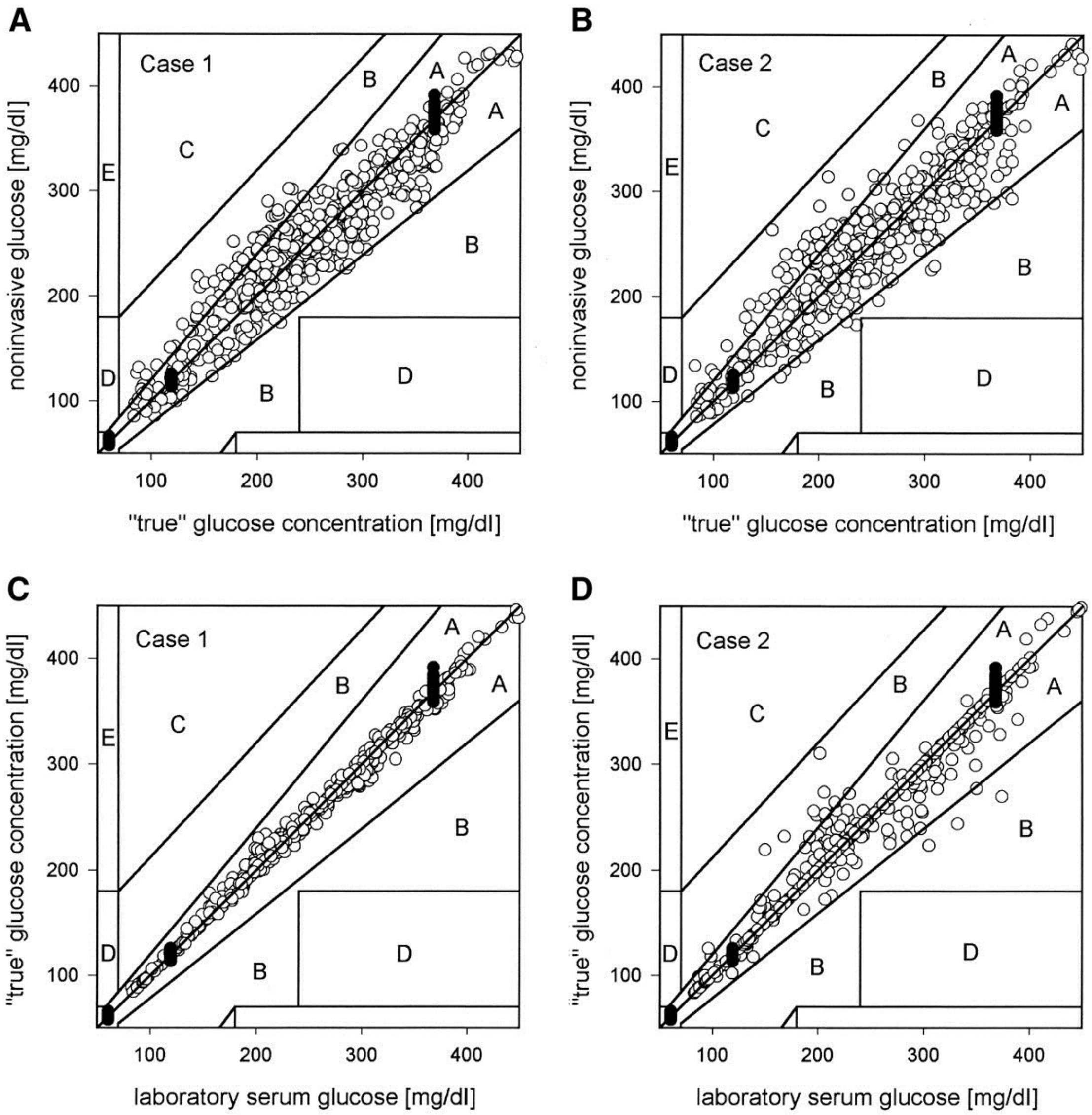


Figure 15: Plot of correlations between "true" serum glucose invasive concentrations and non-invasive glucose concentrations for case 1 (A) and case 2 (B) and corresponding plots of correlations between invasive (laboratory) serum glucose concentrations and "true" serum glucose concentrations for case 1 (C) and case 2 (D).

Based on the results in Figure 11, the prototype gives small different values at all time of measurement for glucose level and skin data shown in Figure 5 above. However, it is considerably acceptable since the readings values is in standard range as the normal level of glucose level in Table 2 above. According to R. Ferber et al. (2013), the patients can being detected early if they are having diabetes or not by the reading of the glucose level on the results. To ensure the usability of the developed machine, the reliability test for systolic and diastolic heart rate measurement has been carried out using statistic software package (SPSS) and the results show that the glucose level respectively, which is very small and still in the acceptable range. The proposed device could be used for commercialization of glucose level measurement and future reference for technical students and researchers.

5.0 Conclusion and future work

There are three major conclusions can be drawn from this project. Firstly, the developed device exhibits a full working system. The system which operates on oscillometric principle is suitable to be located at any medical institutions such as private clinics, government hospital and even can be employed at home. It is also suggested that by using this instrument, people may save their time to travel, and get their blood pressure being check regularly. Indirectly, this shows the benefit of proposed system to meet the demand of health. Secondly, the developed device adapted the wireless technology and using smart phone which enable the user to view the previous results of blood pressure at any time on the smart phone. This makes the results more valuable for future reference. Thirdly, it can be seen that the machine proposed new prototype for medical instrument which can be used as a medium for Telemedicine application. Furthermore, this instrument has a potential to be improved in the future.

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