Pertanika J. Sci. & Technol. 28 (S2): 13 - 24 (2020)

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Proposal of Blood Glucose Control and Exercise Therapy Support System Using Non-invasive Blood Glucose Meter

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ABSTRACT

According to WHO, 420 million adults worldwide are suffering from diabetes. The diabetic patient should regularly verify and control their blood glucose levels. However, the existing blood glucose meters use a needle to collect blood, thus causing problems such as pain and infections. A non-invasive blood glucose meter is a measuring instrument that can avoid these problems, but such an instrument has not been developed to date. Diabetic patients should ensure blood glucose control and exercise therapy: however, the difficulty of management and lack of guidance on exercise therapy are problematic issues that need to be overcome. In this study, a non-invasive blood glucose meter and blood glucose control system has been developed, which can be used along with a healthcare sensor equipped with a non-invasive blood glucose measurement function.

Keywords: Blood glucose, blood glucose monitoring, MHC, non-invasive

ARTICLE INFO

Article history:
Received: 10 February 2020
Accepted: 13 November 2020
Published: 31 December 2020

DOI: https://doi.org/10.47836/pjst.28.S2.02

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INTRODUCTION

Diabetes is one of the top ten causes of death. World Health Organization (WHO) has announced that 420 million adults worldwide suffer from diabetes. (World Health Organization [WHO], 2017). The treatment of diabetic patients is aimed at preventing the development and exacerbation of complications that are characteristic of diabetes and those that are

ISSN: 0128-7680
e-ISSN: 2231-8526

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more likely to occur with diabetes, thus maintaining a quality of life similar to that of healthy people (Haneda et al., 2018). For diabetes management, blood glucose levels must be measured on a regular basis. Henson et al. (2016) studied changes in blood glucose levels in postmenopausal women at high risk for type 2 diabetes in three patterns. The pattern was 7.5 hours of continuous sitting (Pattern 1), 5 minutes of standing (Pattern 2) every 30 minutes, and 5 minutes of walking (Pattern 3) every 30 minutes. The area under the curve of blood glucose was reduced by approximately 30% in pattern 2 and pattern 3 compared to pattern 1 (Henson et al., 2016). The Honda et al. (2016) study also investigated whether short-term stair climbing at 60 and 120 minutes postprandial promoted postprandial hypoglycemia in patients with type 2 diabetes. As a result, the blood glucose level during stair ascent and the descent was significantly lower than that during postprandial rest (Honda et al., 2016). In addition, the effectiveness of physical exercise and aerobic exercise for treating and preventing diabetes has been confirmed, and exercise therapy is considered as the basic treatment of diabetes along with diet therapy. (Kodama et al., 2013; Sone et al., 2013). Therefore, diabetic patients must measure blood glucose levels, and control trends in blood glucose levels, exercise, and diet to prevent diabetes from worsening.

Currently, self-monitoring blood glucose meters that can measure blood glucose levels at home are available commercially. Using such meters, the blood glucose level can be confirmed: however current blood glucose self-monitoring devices require a blood sample from a fingertip using a needle: consequently, various problems have arisen (Patton & Clements, 2012; Vashist, 2012). First, because the measurement is performed using a needle, it is painful and the patient is stressed during each measurement. Both needles and test strips are expensive because they are disposable: however, they can cause infections when blood is drawn. Moreover, for diabetes management, depending on the severity of the disease, continuous blood glucose monitoring and blood glucose measurements are required several times a day, which may cause inflammation in the blood collection area. To solve these problems, an inexpensive measuring instrument is required, which does not require replacement of needle or test paper for each measurement, does not cause any sanitary problems, and does not require blood collection, and can be easily measured at home. For a long time, such devices are called noninvasive blood glucose meters and have been studied. Major noninvasive methods of measuring blood glucose include metabolic heat conformation (MHC) and optical techniques (Kit & Kassim, 2013; Megha & Joshi, 2015; Villena et al., 2019). In this study, MHC technology is used, which is advantageous in the miniaturization of the sensor. In addition to developing a non-invasive blood glucose meter, the simplification of blood glucose level management is another problem that needs to be solved. Arakawa et al. (2015) reported that patients receiving exercise therapy had lower levels of hemoglobin A1c (HbA1c) and frequent instructions. However, Arakawa et al. (2015) reported that exercise therapy for diabetes required less frequent instruction than diet therapy and that there was no specialist in exercise instruction at medical institutions. Furthermore, it is impossible to provide support for exercise therapy for patients with diabetes who are being treated at home because of their health conditions. In this study, we focus on glycemic control in diabetic patients and develop a new system for glycemic control using smartphones and support of exercise therapy.

MATERIALS AND METHODS

Figure 1 shows the system configuration of this system, which is a configuration diagram of a new blood sugar management system developed by the authors. It comprises two systems: a healthcare sensor and a blood glucose control system, both of which have been developed by the authors.

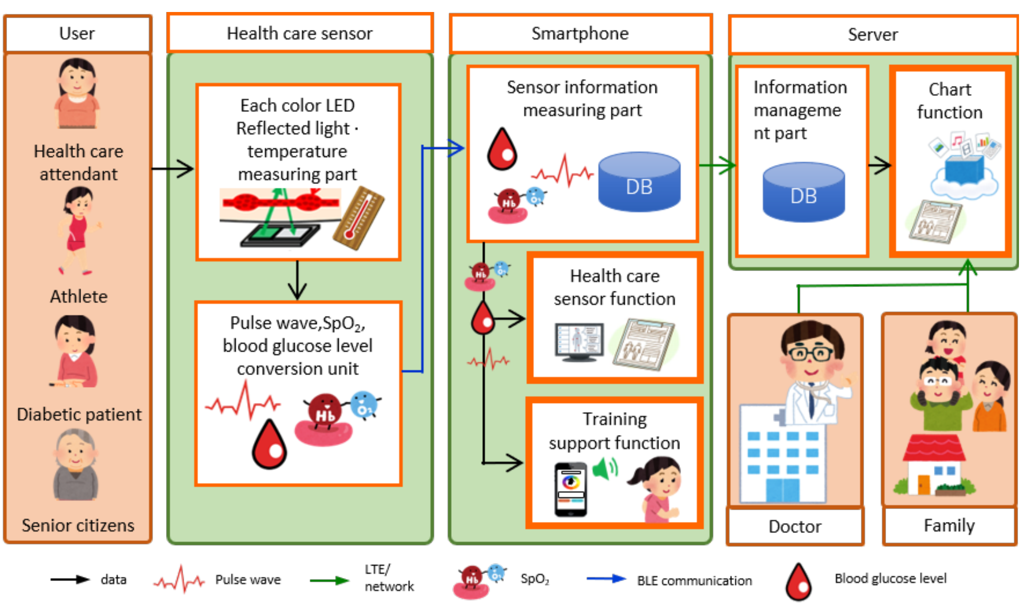

Figure 1.System configuration

Non-invasive Measurement of Blood Glucose

Figure 2 shows the appearance of the healthcare sensor and the equipment used is shown in Table 1. The sensor can measure blood glucose, blood oxygen (SPO2), and heart rate, and the results are used for a blood glucose management system. This sensor can be used by connecting the power supply. You can measure it by operating the measuring instrument from your smartphone and placing your finger on the sensor. The measurement result is transmitted to the smartphone and can be confirmed. MHC technology, which uses MHC technology to measure blood glucose levels, is based on a correlation between glucose levels in the body and the amount of heat released by the body, both of which can be predicted from heat radiation and heat convection (Kit & Kassim, 2013). Heat radiation can be measured using Stefan–Boltzmann's law and is determined as follows:

$$hr = \rho \times \sigma \times (Ts^4 - To^4) \qquad [1]$$

where hr (W/m2) is heat radiation, ρ is the reflection coefficient of the skin surface, σ is Stefan Boltzmann constant, Ts (° C) is the surface temperature, and To (° C) is the ambient temperature.

The thermal convection is obtained as follows.

$$hc = h \times (Ts - To) \qquad [2]$$

where hc (W/m2) is heat convection and h is a heat transfer coefficient.

The formula for calculating the blood glucose level can be derived by performing a linear regression analysis based on the blood glucose level measured with an existing blood glucose meter.

$$\text{Glucose Level} = A + hr * x1 + hc * x2 \qquad [3]$$

In this case, A, x1, and x2 are values derived using linear regression analysis.

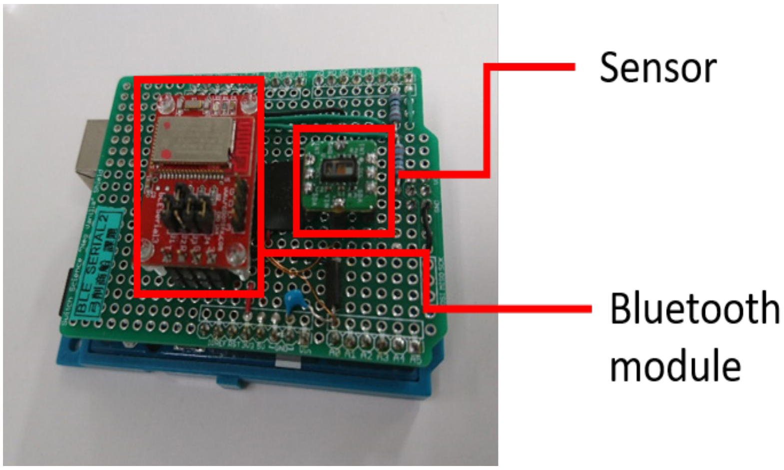

Figure 2. Healthcare sensor (appearance)

Table 1
Noninvasive blood glucose meter (equipment used)

Equipment name	Model number
Microcomputer	Arduino UNO
Reflective sensor	MAX30102
Temperature sensor	NTC thermistor
Communication	BLE Module

Accuracy Evaluation

In this study, we evaluated the accuracy of a non-invasive blood glucose meter mounted on a healthcare sensor. The EGA method of the ISO standard is used for accuracy evaluation. The EGA method is shown in Table 2. The EGA method can be evaluated on a scale of 5 from A to E, and used in medical applications if a value of 99% is plotted in zone A. When values are plotted in zones A and B, those levels can be used to measure daily life (Boren et al., 2010; Kit & Kassim, 2013).

Table 2
Definition of EGA method

Area	Description	Surveillance error grid (Degree of risk)
A	The estimated blood glucose level deviates about ± 20% from the actual value. (Clinically correct decisions)	No risk
B	Self-monitoring device giving predictive blood glucose level degree results differ by more than 20% from an actual value. (be available for daily use)	Mild risk
C	Poor results of self-monitoring equipment	Moderate risk
D	Dangerous failure to detect and treat	High risk
E	False blood glucose levels causing serious problems in diabetes management.	Extreme risk

Blood Glucose Control System

Table 3 shows a comparison with similar systems. The system can be linked to a non-invasive blood glucose meter to provide the visualization of measurement data and support for exercise therapy. There is also no system that cooperates with a blood glucose meter to control blood glucose levels or support exercise therapy. This, therefore, is the first attempt.

Table 3
Comparison with similar systems

	Measurement of glucose levels	Noninvasive	Measurement of SPO2 and heart rate	Aerobic exercise support	Anaerobic exercise support
This system	○	○	○	○	○
Apple Watch	Unknown	○	×	×	×
MOCA heart	×	-	○	○	×
FreeStyle Libre	○	×	×	×	×
Run Keeper	×	-	×	○	×
KAATSU CYCLE	×	-	×	×	○

For glycemic control, HbA1c is the most important value for diabetics. This system also introduces HbA1c and calculates it as follows (Nathan et al., 2008):

$$\text{HbA1c} = (X + 46.7) / 28.7 \qquad [4]$$

where X is the mean blood glucose level at 1 ~ 2 months.

RESULTS AND DISCUSSIONS

First, the measurement accuracy of the healthcare sensor is explained. Table 4 shows the parameters and error rates. For heart rate and blood oxygen concentration, 25 samples were taken from 1 male, and error rates were calculated. As a result, it was confirmed that these two parameters were very accurate and practical. Subsequently, 25 samples were taken from one male to investigate the accuracy of blood glucose measurements. On the blood sugar level, the accuracy evaluation was carried out using the EGA method of the ISO standard. The contents of zones A to E of the EGA method are shown in Table 2. In the graph of the EGA method, the vertical axis indicates the predicted blood glucose level, and the horizontal axis indicates the blood glucose level measured by an existing invasive blood glucose meter (true blood glucose level). This predicted blood glucose level was calculated using Equation 3 based on the temperature measured using the system. The results are shown in Figure 3. In Figure 3, values of 80% were plotted for Zone A and 20% for Zone B. The RMSE (Root Mean Squared Error) was 25.8. From Figure. 3, it was confirmed that the accuracy of this system is at a level usable in daily life.

Table 4
The error of each parameter

	Glucose Level	SPO2	Heart Rate
Error rate	9.7%	−0.04%	0.78%
subject	25 samples per man	25 samples per man	25 samples per man

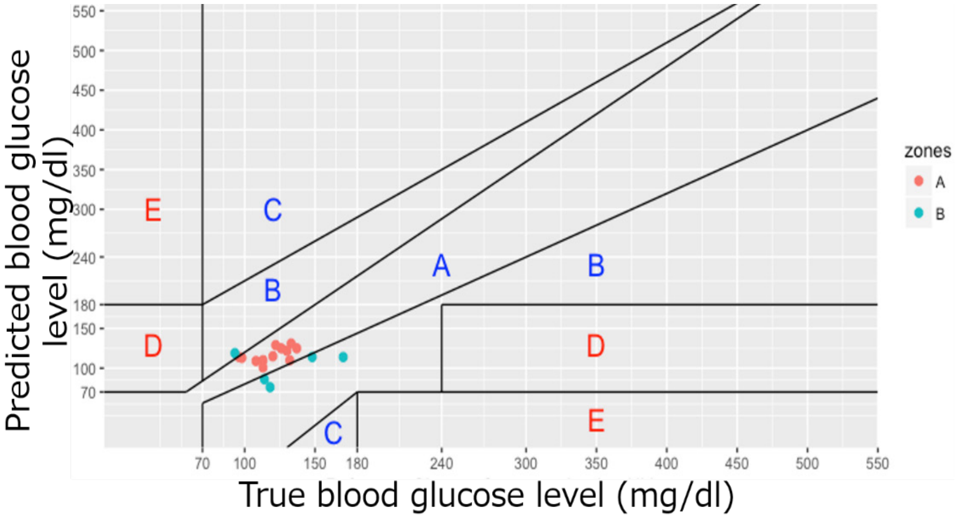

Figure 3. Accuracy evaluation using the EGA method

Next, the blood sugar management system is described. This blood sugar control system has three features. First, the data measured by the health sensor is automatically stored on the smartphone. When measuring blood glucose levels, we use a smartphone to operate a healthcare sensor. When measuring, one finger is placed on the health sensor. After about 10 seconds, the phone will show the results. The values measured here are blood glucose level, blood oxygen concentration, and heart rate. The results are stored on the smartphone and can be viewed at any time. Conventional blood glucose meters can only confirm blood glucose levels, and advice can be obtained from the state of blood glucose levels only when a person visits a hospital. In this system, as shown in Figure 4 and Figure 5, however, one can check at a glance whether the blood glucose level is high or low and make a simple comment according to the health condition. Consequently, one can grasp the state of oneself at the time of measurement without seeing a doctor. Since it is equipped with a memo function, it also becomes easy to explain the situation to the doctor at the hospital by noting the point of concern at the time of measurement.

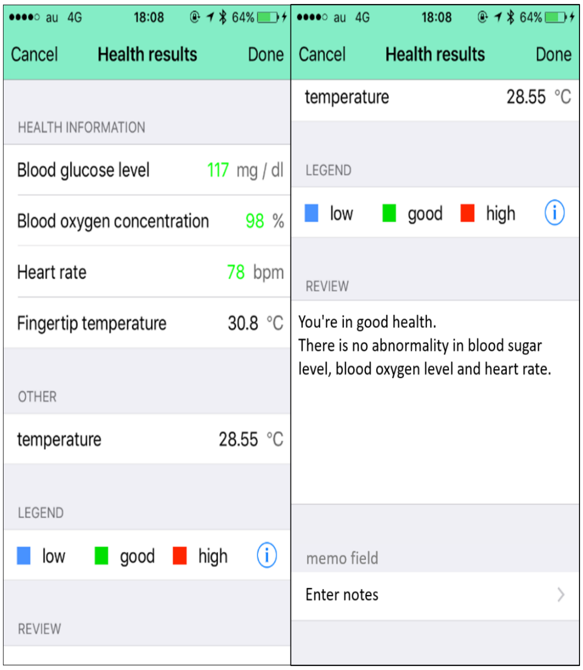

Figure 4. Diagnosis result screen

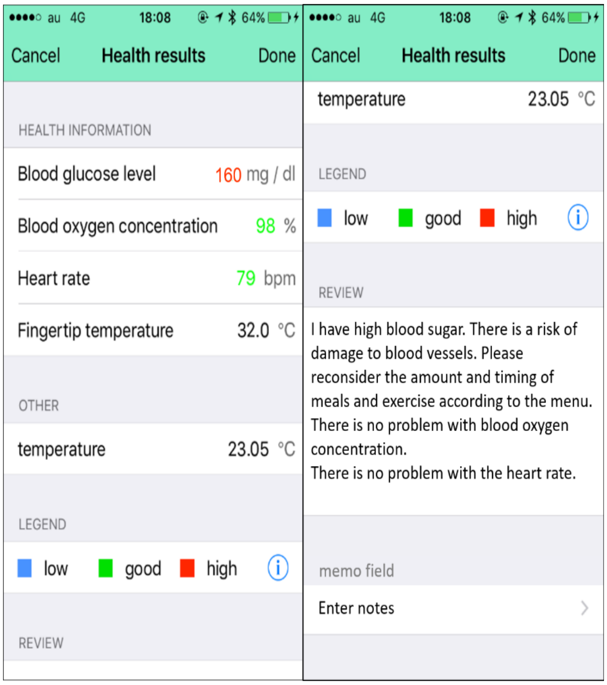

Figure 5. Diagnosis result screen (case of hyperglycemia)

The second is the training support function. Figure 6 shows a flowchart of the training support function, which is primarily based on exercise therapy in diabetics. First, we identify the patient's chronic illness and suggest a safe training menu based on the values obtained from the healthcare sensor. For example, if the previous blood sugar level is high, it is dangerous to do strenuous exercise and you should be advised to do light or no exercise. The same applies to cases of chronic diseases. This function also provides support during exercise. During exercise, it supports sugar, hydration, and pace. After exercise, save the day's distance traveled and time spent exercising, and use the healthcare sensor to reassess health. Consequently, it becomes possible to support exercise therapy that is currently not being performed due to insufficient guidance. It also proposes a menu to lower blood glucose levels based on the theory of exercise therapy, which is expected to spread among diabetic patients.

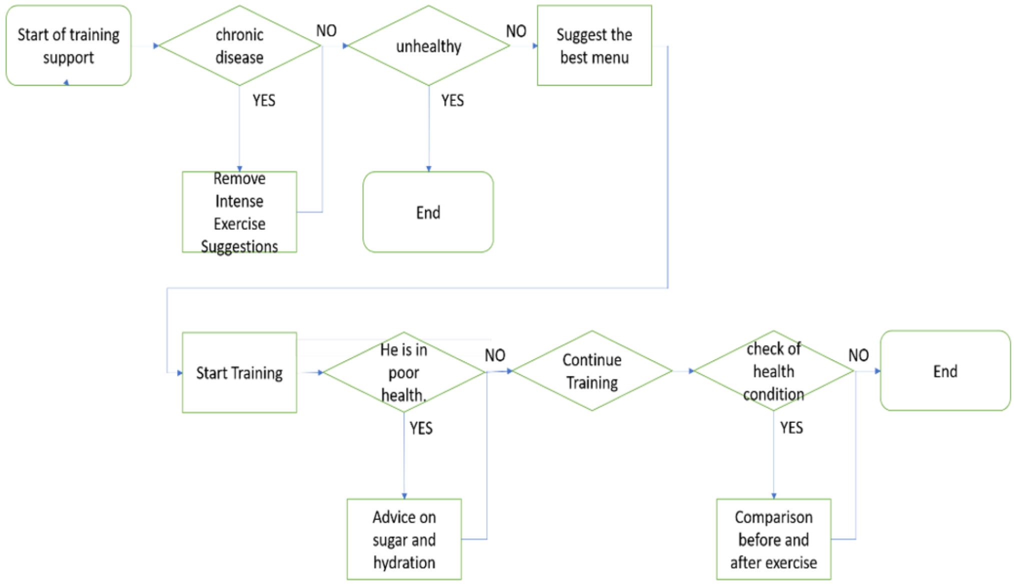

Figure 6. Exercise support flowchart

The third is the chart function. The contents of this function are different for each measuring object. In order to control diabetes, it is necessary not only to measure the blood sugar level but also to emphasize the change. Therefore, changes in blood glucose levels with time, changes before and after meals, and HbA1c are calculated. Figure 7 shows the display contents of the blood sugar level measurement result. As I explained earlier, the measurement results so far can be checked graphically. The HbA1c, which is an important value for patients with diabetes, is also specifically calculated, and care is taken to make it easy for patients with diabetes to know their HbA1c levels even at home.

Figure 7. Chart function

Figure 8 shows the blood oxygen concentration. Since the blood oxygen concentration is dangerous when it is low in the exercise therapy in the diabetes mellitus treatment, it is possible to confirm the record of minimum value and average value. The progress graph of the graph is not displayed, because it is not necessary to control the time change of the blood oxygen concentration. The pulse rate is not continuously managed in this system, so there is no graph display function.

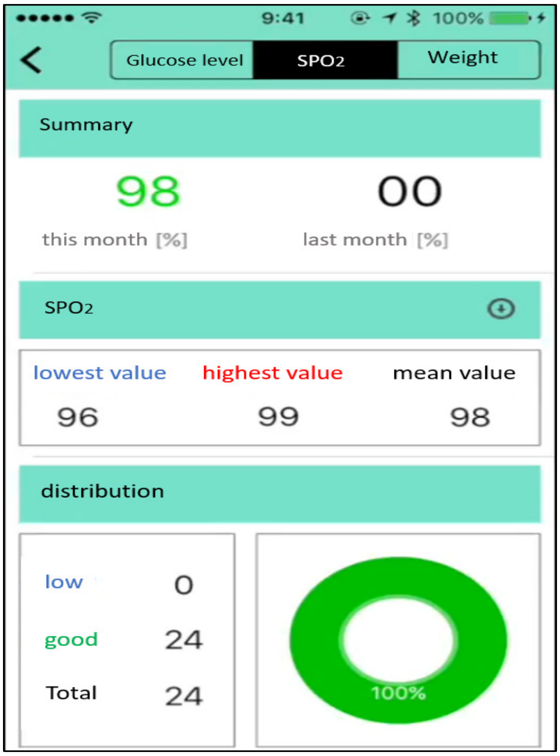

Figure 8. Diagnosis result screen (SPO2)

CONCLUSION

In this paper, we focus on glycemic control in diabetic patients and develop a new system to support glycemic control and exercise therapy using smartphones. Noninvasive blood glucose measurements of healthcare sensors cannot be used for medical purposes because of their accuracy in daily life. We, however, are confident that this system could support the currently insufficient exercise therapy and lead to the spread of health management and exercise therapy.

ACKNOWLEDGMENT

We want to express our gratitude to the participants who participated in the accurate evaluation of this system.

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