Non-invasive Glucose Monitoring System Utilizing Near-Infrared Technology

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Non-invasive Glucose Monitoring System Utilizing Near-Infrared Technology

Duc Trinh-Minh Dinh, Viet Anh Truong, An Nhu-Phu Tran, Hieu Xuan Le, and Hien Thi-Thu Pham

Abstract

Regular monitoring of glucose concentration is essential and urgency, especially diabetics. However, those methods which involve finger puncturing are invasive, expensive as well as painful. Also, there are risks of infectious diseases using these techniques due to the contact of the needle on human skin. This paper proposed a non-invasive glucose monitoring system utilizing the near-infrared (NIR) light to measure the glucose concentration in the human blood. The designed system uses a 980 nm-wavelength NIR LED transmitting through D-glucose phantom samples, a photo-sensor for analyzing the transmitting optical parameters, a filter & an amplifier circuit, and a Nano Arduino microcontroller. For calculating the values of glucose concentration, the R programming with the methodology of the artificial neural network (ANN) was applied. This type of methodology is considered as one of the most useful technique in the world of data analysis and because it is adaptive, learns from the provided information and optimizes for better prediction outcomes. The ANN is used to predict the correlation equation between collected voltage and glucose concentration. The obtained glucose level is demonstrated directly on the system's screen or further sent to the user's mobile phone. The result obtained shows a correlation between the transmittance and the concentration of D-glucose solution. The correlation parameter of the technique is $R^2 = 0.9957$. Despite having the acceptable results, there are still some improvements that could be carried out for more accurate measurement (angle of the LED, a procedure of filtering and amplifying, usage of an optical instrument…). For further investigation and development, it is predicted that the result can be more accurate, precise and sensitivity as much as possible.

Keywords

Near-infrared • Non-invasive • Blood glucose • Diabetes

1 Introduction

Diabetes is a pathological metabolic condition that occurs when the amount of glucose (sugar) in the blood is too high, which affects other organs if not diagnosed and left untreated. Nowadays, it has become a significant health problem globally. Nowadays, the number of people getting diabetes is rising, and the need for the blood glucose monitoring is the obvious outcome. Checking the blood pressure regularly not only let people know what state they are in but also help them to have suitable prevent diabetes [1–5].

With the available devices, the users can check their blood glucose quickly and regularly. The most popular device is the invasive type. The user has to make a finger prick by using a test strip, and the device uses their blood to calculate the glucose amount. Although giving precise results but this method has some disadvantages: not suitable for people who afraid of needles, waste of money and time to buy the test trip, painful and discomfort. Moreover, using the invasive method could increase the risk of infection. Hence, finding another method is the concern at the moment.

Indeed, there is a sharp rise of the non-invasive method for checking the blood glucose level. The majority of these methods is the application of the LED and the properties of light for measurement. These devices can deliver painless and comfortable progress for the users. Although this type of method is new, it shows the potential of making a device which is more user-friendly, painless and could give reliable results.

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The non-invasive method works base on the light properties. For each substance, there is always a specific wavelength at which the absorbance of that substance is that strongest. Each substance has its wavelength. Using this property, the system consists of two main components which are the LED and the photo-sensor. The LED emit the light through the skin area where it is put, and the photo-sensor is placed on the opposite side. By choosing the appropriate wavelength which absorbed mostly by blood glucose, the amount of light that reaches the photo-sensor is calculated and analyzed.

Choosing the appropriate wavelength for the system is the most important key. To achieve the good result, the wavelength must be the one that has the most interaction with blood glucose and also not be affected too much by the other substances. There have been many options for the wavelength that is proposed by the previous research since glucose has light absorption peaks at wavelengths of 940, 1150, 1450, 1536 nm [1–5]. The wavelength of 940 nm is chosen the most in research since, at this wavelength, the attenuation of optical signals by other constituents like platelets, red blood cells or water is at a minimum.

2 Methodology

The proposed system consists of an adapter and a voltage converter for converting 220–24 and 24–5 V for the power supply. A NIR light source and an optical sensor are the main parts of the system. When the light reaches the optical sensor, the signals go through amplifying and filter circuits, and an Arduino is used to convert the data from analog to digital signals. After the processing, the value of blood glucose level is shown on the computer. Figure 1 validates the operation of the system.

2.1 Emitting System

The NIR LED used in the system is TSAL 6100 with the wavelength of 940 nm. This LED has an emitting angle and the power that suitable for the system, and that leads to the decrease of scattering light. A constant current circuit is designed for emission of NIR to minimize the fluctuation in the current through the NIR LED. For this circuit, the BC557 PNP transistor is used along with LM358. LM358 op-amp plays the role as a current stabilizer to adjust the suitable current goes into the LED. The output of LM358 is given to the base of the transistor for controlling the average power transmitted by the NIR LED. Figure 2 demonstrates the emitter circuit diagram.

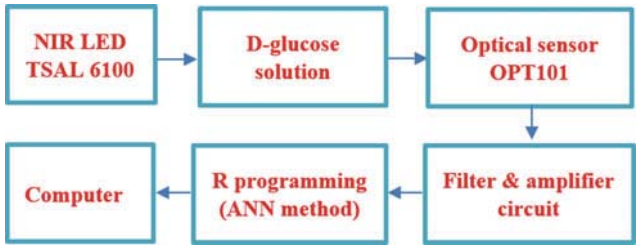

Fig. 1 The block diagram of the system

2.2 Receiving System

The OPT101 is used as the optical sensor. The reason for using this sensor is because the sensitivity is high enough thus it would not be affected too much by another light source from the environment or scattering light. LM358 is also used in the designed circuit. Therefore, the signal collected from the optical sensor is then amplified and filtered. Figure 3 shows the receiver circuit diagram.

2.3 Black Box System

A black box system is built to keep the sample and the sensor from getting noise. There is a slit put in front of the LED, and the size of the slit would fit the emitting angle so the intensity transferred from the LED to sample is the most. The purpose is to focus the light into a line and lead it directly to the sample, and it could reduce the noise since most of the

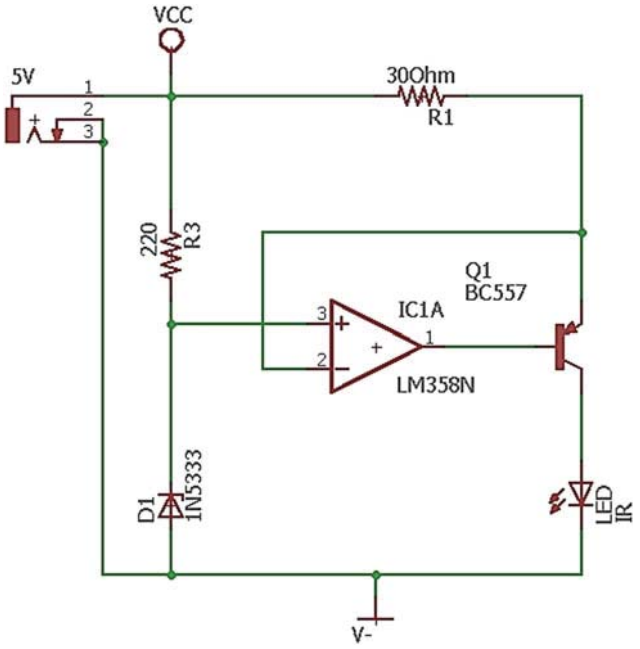

Fig. 2 Emitter circuit

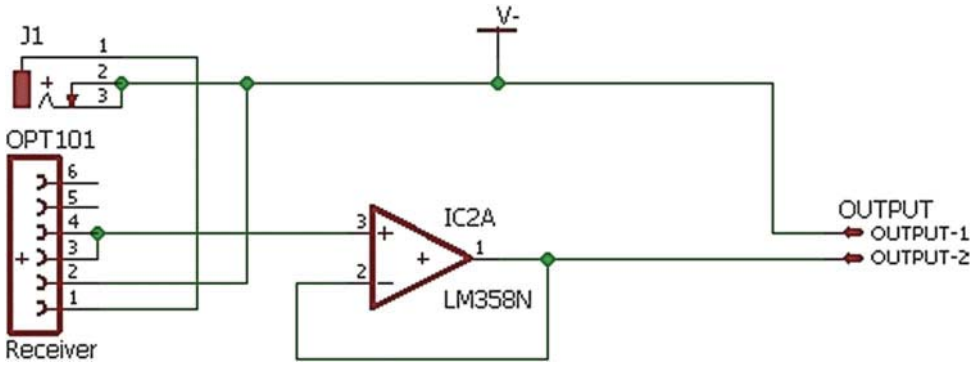

Fig. 3 Receiver circuit

sensitivity contact with the sample. All the light leaving the sample goes into the optical sensor put behind the sample. The box is painted black to absorb the scattering light goes out from the sample. There is an area in the box for putting the circuits. Figure 4 shows the illustration of black box system.

2.4 Analyzing System

The method for processing the data getting from the LED is by using machine learning. ANN method is chosen for processing and analyzes the data since it is more appropriate with the complex data [6]. Figures 5 and 6 show the component of ANN were used in this study.

The network consists of one input layer, one output layer, and several hidden layers. Each input node maps to all hidden nodes, and each hidden node maps to all nodes of the next hidden layers till it reaches the output

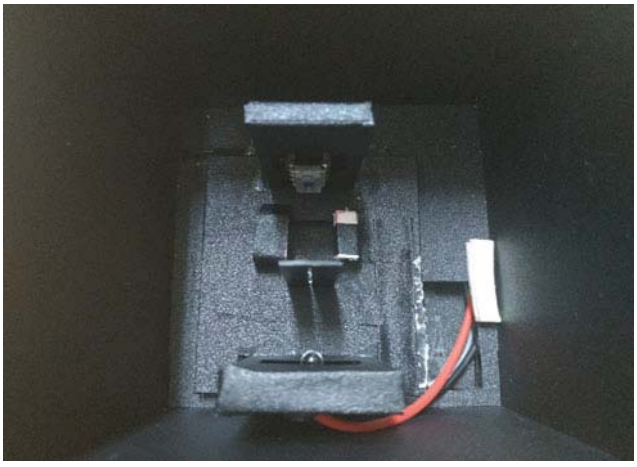

Fig. 4 Black box system

Since one node in hidden layers may connect with several others nodes, the value of that node can be calculated with the formula:

$$Y = f(w1.X1 + w2.X2 + \cdots + Wn.Xn) \quad (1)$$

where Y is the output of that node and X1, X2, …, Xn are the input nodes; W1, W2, …, Wn is the weights corresponding to each node respectively.

The final node- output node is utilized to compare the accuracy of the model to the training data. The weights is updated continuously until we obtain the minimum in "Error estimation" between actual output and model output [6, 7].

$$J(w) = \frac{1}{2}\sum_i \left(target^{(i)} - output^{(i)}\right)^2 \quad (2)$$

where J(w) is the error/loss, target$^{(i)}$ is the actual output and output$^{(i)}$ is the network output.

Following, Fig. 7 shows the flowchart of the ANN network for better illustration

There were D-glucose samples prepared with a variant of concentrations. Every time a sample with known concentration is measured, the output voltage is recorded. After multiple measurements and records for each concentration, a set of data with corresponding output voltages is created for ANN. This set of data is used to train the ANN, and from the trained data, appropriate function and algorithm is generated to calculate the connection between D-glucose concentration and the output voltage. The sample for the training data must be assured with unification (in the way of making the sample: the weight of 12 sample for each concentration must be identical and also the amount of water) to reduce the error between each measurement and increase the accuracy for the predicted result.

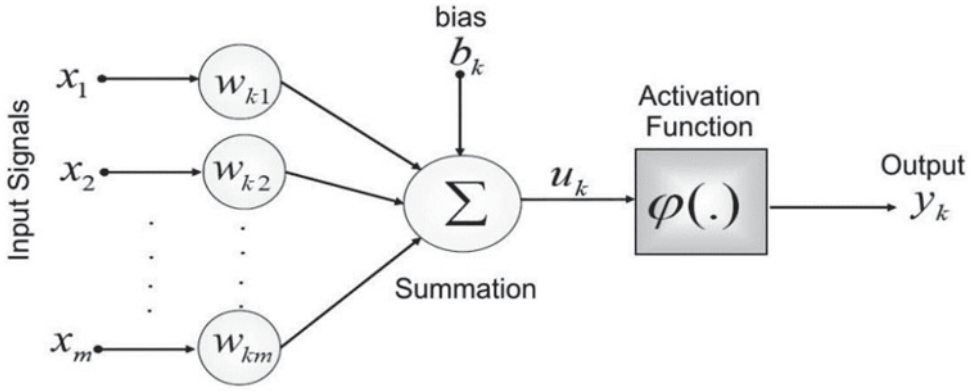

Fig. 5 ANN diagram

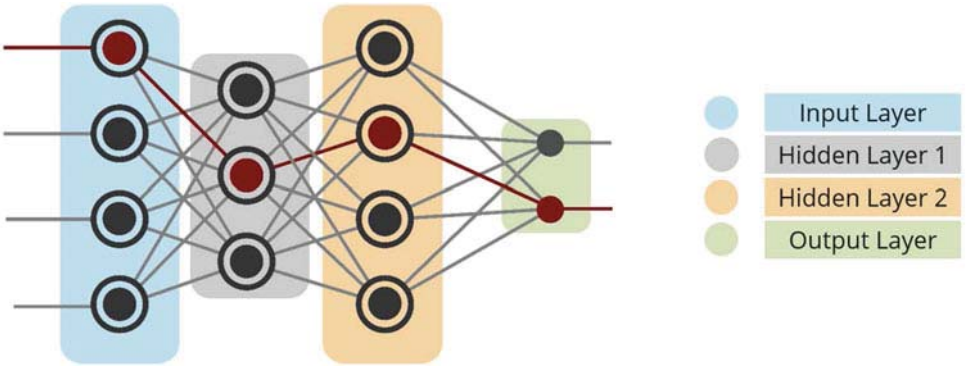

Fig. 6 The layers of ANN

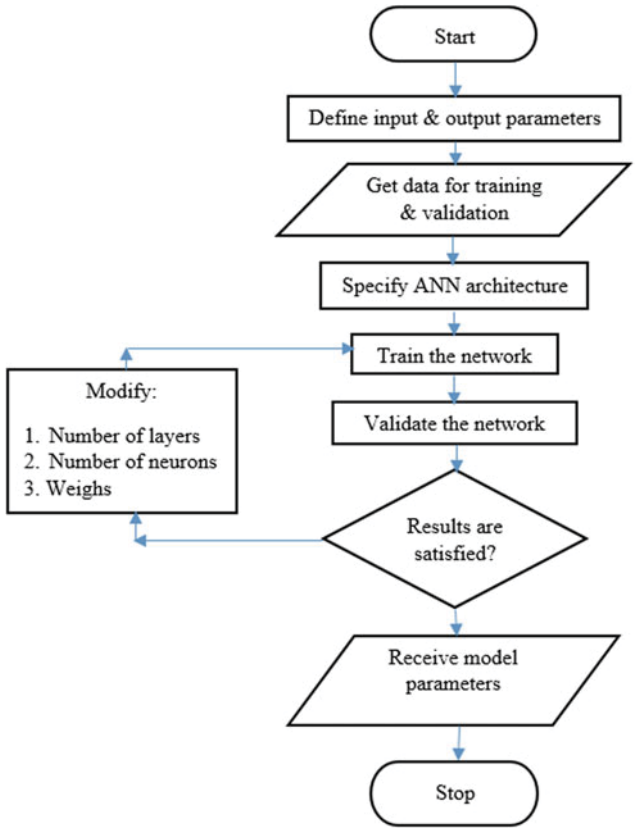

Fig. 7 Flowchart of ANN network

3 Results and Discussion

The results were taken from twelve samples of five different concentrations (500, 1000, 1500, 1800 and 2000 ppm). The mean of each sample were chosen to make the correlation line between the concentration and the output voltage. Table 1 and Fig. 8 show the collected data (with standard deviation) and the correlation.

As data at two concentrations 1500 and 1800 ppm shows no linearity, the 1500 ppm concentration is removed in order to increase the accuracy of the system (by comparing the R^2 of the model while removing 1500 and 1800 ppm respectively). Figure 9 shows the fit line and trend line of the data after removing 1500 ppm concentration point.

The results illustrate the linear correlation of the output voltage and glucose concentration chosen from the data table. It reveals that the more concentration of the sample, the more output voltage measured. The trend line has the $R^2 = 0.9957$ comparing with another reliable source is the UV-VIS 730 machine with $R^2 = 0.9999$.

The results approve that wavelength and the method of processing chosen for the research are appropriate and have the potential to develop further. As the few number of samples, the use of ANN cannot be optimized and the produced result is not enough sensitivity. Some improvements

Table 1 The collected data table

Samples (ppm)	1	2	3	4	5	6	7	8	9	10	11	12
500	3.936	3.937	3.945	3.945	3.924	3.924	3.915	3.915	3.922	3.921	3.922	3.93
1000	3.955	3.942	3.945	3.958	3.941	3.942	3.94	3.932	3.933	3.939	3.948	3.945
1500	3.971	3.979	3.969	3.979	3.979	3.97	3.963	3.974	3.98	3.976	3.98	3.977
1800	3.976	3.972	3.979	3.978	3.979	3.974	3.975	3.971	3.98	3.972	3.973	3.972
2000	3.985	3.987	3.985	3.984	3.982	3.987	3.983	3.978	3.981	3.987	3.988	3.983

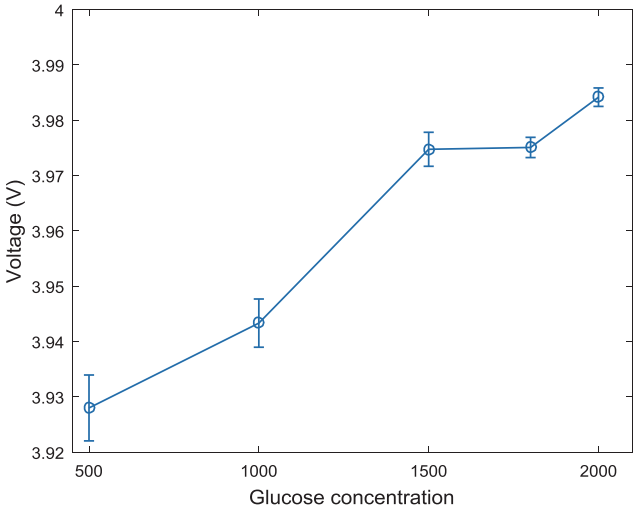

Fig. 8 Correlation between the output voltage and concentration

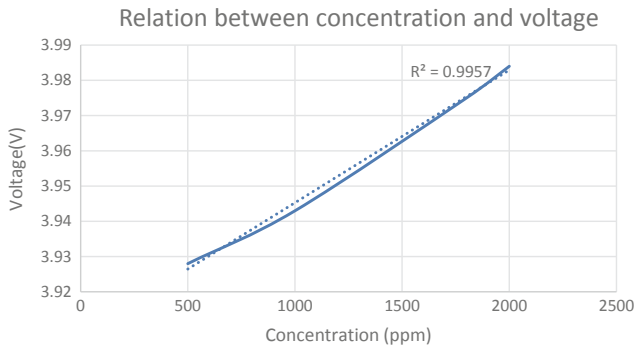

Fig. 9 Model after removing 1500 ppm data

should be carried out for more accurate and reliable results in future: the emitting angle of the LED, the amplifying and filtering circuit, the structure of the black box, increasing the size of the data set for the better fit with ANN in predicting the fit line, usage of another optical instrument.

4 Conclusion

The work in this study provides the way for measuring the glucose concentration non-invasively. For further development, the system is expected to be able to work with more complicated solutions such as a microsphere, animal blood as well as other liquid composition in the human body.

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Conflict of Interest The authors declare that they have no conflict of interest.

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