The Noninvasive Blood Glucose Monitoring by Means of Near Infrared Sensors

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***Abstract*—Diabetes is a type of metabolic disease that causes a high blood glucose level that wildly found in many countries. Blood glucose measurement is necessary for diabetes patients to check how much glucose is present in the blood. The typical method to measure blood glucose level is an invasive method that gives a highly accurate result, but the patients get suffer from physical pains and it has a higher risk of infection. This research presents an alternative method, which is noninvasive blood glucose monitoring by means of Near infrared sensors based on 940nm near infrared spectrum and an artificial neural network analysis. The concept is focusing on glucose absorbance detection when the spectrum passes through the patient's finger. In processing the signals, the wavelet's transformation is selected to do signal conditioning and extract four eigenvalues. The four eigenvalues are the key features for training the artificial neural network analysis model that gives an efficiency prediction algorithm of blood glucose level. The experiment shows that the accuracy of the noninvasive method that has the approximate regression value is 0.9534. The noninvasive blood glucose monitoring by means of Near infrared sensors causes less pain and lower risk of infection when compared with the invasive method.**

***Index Terms*—diabetes, Near Infrared Sensors (NIR), Artificial Neural Network (ANN), wavelet's transformation**

I. Introduction

Diabetes is a chronic condition associated with abnormally high blood glucose levels. The disease occurs by an inadequate insulin production by pancreases lead to an absence or insufficiency insulin for cell bodies responses [1]. Diabetes disease can be managed, but it is urgent because it is a major contributor to foot infection, heart disease, stroke, blindness, kidney failure and other health problems. Mostly, the blood glucose level can be measured by prick a lancet, a small and sharp needle, to patient's finger and then put a drop of blood on a disposable test strip, but this invasive method effects of painful, finger infection and toxic waste from lancer and disposable stip. Furthermore, the test strip for the invasive blood glucose has an expired date and the cost is expensive.

As mentioned, bring out the concept of the alternative blood glucose measurement method that can improve the unsatisfactory traditional method by applies the new technology into this field. In these recent times, there have some research demonstrated evidence that glucose has an absorbance in range of infrared wavelength [2], [3], but the research about the effective noninvasive blood glucose by means of infrared sensors does not exist yet. For these reasons, the Artificial Intelligence is introduced in this research for analyze and predict the blood glucose level in range of effective performance.

This research is a study about the noninvasive blood glucose monitoring by means of Near infrared sensors. Based on 940nm near infrared spectrum, which can transmit through the human fingertip, and the artificial neural network algorithm model to analyze and gives highly accurate prediction algorithm of blood glucose levels. In addition, this alternative method is reducing a chance of fingertip infection from the lancet, causes less pain when compared with the invasive method, also improve the problems of toxic wasted from the lancet and disposable test strip.

The research is divided into 4 main parts including signal detection, feature extraction, classification, and prediction. Firstly, the transmitted near infrared was detected by photoreceptor, which connected to the Raspberry pi. After that, the collected signal took part in feature extraction [4] by using wavelet toolbox, algorithms for continuous wavelet analysis, wavelet coherence, synchrosqueezing, and data-adaptive time-frequency analysis [5], to reduce signal dimension [6]; the Haar Mother wavelet provide the most efficiency feature for signal processing [7]. The key features is then applied to classification and prediction system by using the Artificial Neural Network to trained the system until get the desire performance [8]. Consequently, all the process provide the noninvasive blood glucose monitoring system, which has a high accuracy and gives regressions value at 0.9534.

II. Materials

A. TSAL6400

TSAL6400 is a 940 nm infrared emitting diode that suitable for this project because it is in range of glucose absorbance. Moreover, the features of this give high reliability, high radiant intensity, wildly use, and affordable price.

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B. BPX65

BPX65, a silicon PIN diode, was selected as a photodetector because of its sensitivity and accuracy performance.

C. Raspberry Pi Model B

Raspberry pi is a credit card-sized computer that can plug with the monitor, keyboard and mouse to work as personal computer. The board was invited to the project as the reading and processing of signal.

D. MATLAB R2018a

MATLAB is a software that take part of classification and regression analysis, also the Artificial Neural Network to predict the blood glucose level in a desire performance.

III. Methodology and Experimental

The silicon PIN photodiode and pulse oximeter module were used to detect signals of the varying glucose concentration between 100-250 mg/dL with 10 replications for each. The signals were conversed from analog to digital by MCP3008 before passed to Raspberry Pi3. Sample signals were divided into two sets equally. In model training phase MATLAB 2018a and the first dataset were deployed to develop features extraction algorithms and train Double-Artificial Neural Network model which is contained of classification and regression model. Derived feature process was application of wavelet transform and principle component analysis to preprocess the data before send to build mathematics model. Another dataset was deployed in model testing phase in order to verify the prediction skill of exported models then generated C code of the best performance model to combine with data collecting part in microcontroller as shown in Fig. 1 and Fig. 2.

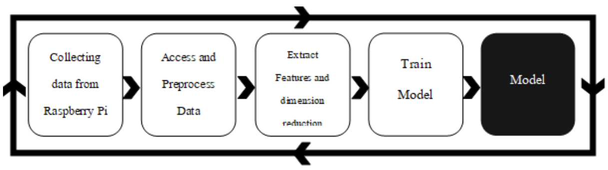

Figure 1. Training process: Iterate until achieve satisfactory performance.

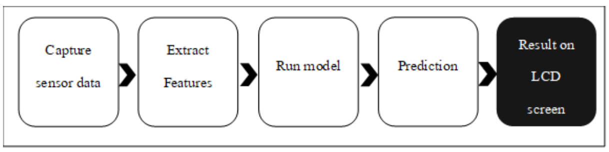

Figure 2. Prediction process: Integrate the trained model into the module.

A. Signal Detection Circuit

In this research, the two sensors module are used for the data collecting to get the training signal for ANN algorithm. The near infrared sensors,940nm wavelength, measured the key signal and the MAX3100 pulse oximeter module, contains 880nm infrared wavelength and 660nm red wavelength, that has the infrared sensors and red sensors inside measured the reference signal.

The near infrared sensor is connected to the Raspberry Pi for reading signals. Nevertheless, the Raspberry Pi does not have the analog read pin, for that reason the MCP3008 analog to digital convert is connected to the circuit. Fig. 3 show the circuit diagram.

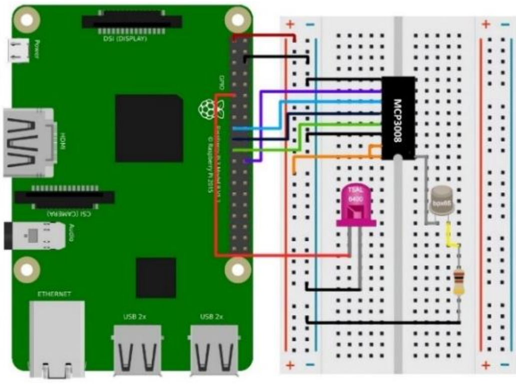

Figure 3. Infrared sensors connected to Raspberry Pi circuit diagram

The BPX65 is connected to CH0 of MCP3008 analog to digital converter to detect the signals from the photodiode then the converter will transform the signal to digital and the TSAL6400 infrared photodiode is connected to GPIO17 of Raspberry Pi board to be the light source of circuit.

BPX65 silicon photodetector will detect the infrared signal from TSAL6400 that pass through the finger in a form of voltage by:

$$V_o = input * \left(\frac{3.3}{1023}\right)$$

The MAX3100 pulse oximeter module is connected to the Arduino Nano, a small, complete, and breadboard-friendly board based on the ATmega328P [10], to read the SpO_2 signal in both of 660nm and 880 nm wavelength as the signal reference for ANN algorithm training. The module is connected as shown in Fig. 4.

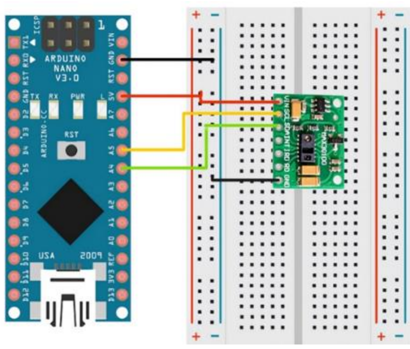

Figure 4. Pulse oximeter module connected to Arduino nano circuit diagram.

The pulse oximeter module gives 2 different signals, one is from the 660nm wavelength red light and another one is from the 880nm wavelength infrared light. It gives the results of light absorbance of human blood.

In this research, the obtained signal of each sensors will be the key and the reference signals for machine learning by extracting features, wavelet selection and artificial neural network in MATLAB.

B. Collecting Data by in Vitro Testing

In vitro testing referred to the studies of biological properties that are done in a test tube instead of living things. In this research, the glucose absorbance testing is done by in vitro testing.

D-Glucose powder (C6H12O6) is a solute for this experiment dissolve into water (H2O) in concentration that vary in range of 100mg/dL – 250mg/dL, added concentration for 10mg/dL in each. The test tube is place between infrared sensors and photodetector to measure to glucose absorbance.

The 940nm infrared light will pass through the test tube and the concentration of solution caused the beam to weaken. Raspberry Pi read the signals from photodetector in 30 seconds with 10 replications for each concentration and record the signals as voltage output.

Also, the MAX3100 pulse oximeter module is placed like infrared sensors. The red and infra red sensors in module detect the glucose absorbance in each wavelength and read the signal as raw data via Arduino Nano board.

After repeating all process for every concentration will get the 16 set of data with 10 replications for each. In one replication set contains 320×1 array of output signals. Then all 16 set of data is left for signal processing in MATLAB part.

C. Feature Extraction

The collected data with 10 replications in each concentration from in vitro test were passed through the feature extraction algorithm in MATLAB R2018a to get the input features vector for neural network in the next step. It is the loop which consist of wavelet transform, statistics equations and signal processing tools. The process of this algorithm is beginning with the 3 difference wavelength signals from the Raspberry Pi were checked the undefined or unpresentable values (NAN). Then decomposed the signal by using Discrete Wavelet Transform (DWT) with Haar mother wavelet due to the similarity of it and our signal into 5 levels. We decide to reconstruct the level 2 detail coefficient of the decomposed signal to estimate an effective component of the signals by using the Inverse Discrete Wavelet Transform (IDWT). The reconstructed signals then were used to calculate or analyze the features in time domain, frequency domain and statistical. The feature matrix in dimension of 9x3 for each time of measurement were next reduced size by using the Principle Component Analysis (PCA). The feature matrix is composed of signal with 3 different of wavelength lies in 3 columns and there 9 features were lies in 9 rows. Therefore, the PCA is introduced to reduce matrix into size of 9x1 to be used as the input for Neural Network training.

D. Classification and Regression Artificial Neural Network Training

Double neural network was in introduced to the research to predict the blood glucose level with more accurately. In the double artificial neural network is consist of two mainly algorithms, one is artificial neural network classification algorithm and the other one is artificial neural network regression algorithm. The two main artificial neural network algorithms were designed for classify the range of blood glucose and predict the concentration of it by using features information for the network. In this part MATLAB R2018a were applied to analyze and develop the model. The process is show in Fig. 5.

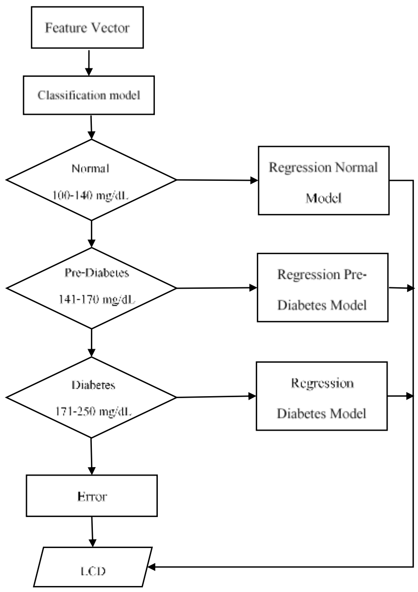

Figure 5. Flow chart of working process.

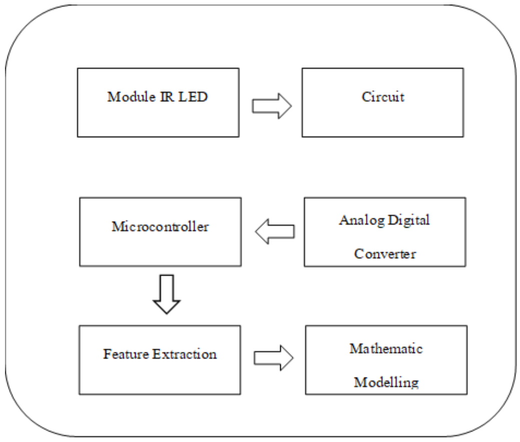

Figure 6. Prediction system.

To create the prediction system, the classification and regression models from previous steps and include the features extraction algorithm were combined. Begin with the new signal or data from measurement will pass through the features extraction algorithm to get the features vector or eigenvalues of it. The eigenvalues will be feed to the prediction model. Inside the prediction model the eigenvalues will be classified which groups it belongs to by classification model. Then the regression model will be applying to the eigenvalues depend on the group to predict the concentration of it. After that the result of the group and the concentration of glucose will be sent to perform the result on the connected LCD screen on the raspberry Pi. The process is show in Fig. 6.

IV. Results

In result, Discrete Wavelet Transforms (DWT) was applied in feature extraction step in order to cut up the signals into different frequencies. The mother wavelet is an important tool for DWT to move along the time series signals. In this project, mother wavelets in the Dubecies were considered to find the most suitable mother wavelet for our sample signal. The results point out that the Haar mother wavelet is the most suitable for our work due to giving the least mean square error of measuring wavelet coefficients from sample signals decomposition and reconstructed signals when applied it.

In Classification Neural Network model results as show in Fig. 7 indicate that model no. 2 gave the highest percentage accuracy among the three exported best performance model and also showed the most efficient model skill after tested with unrelated training dataset.

Figure 7. The confusion matrix of classification model no. 2.

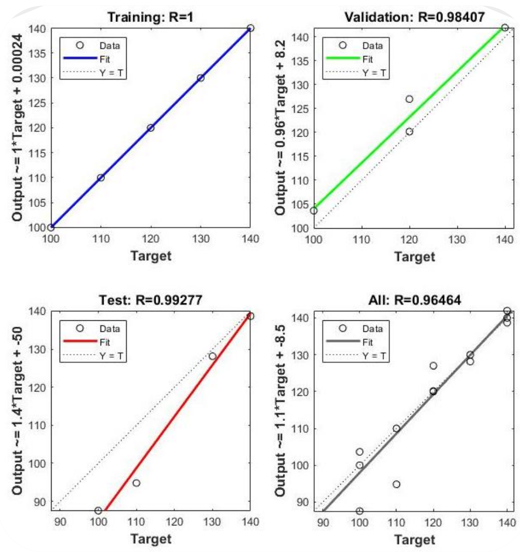

Figure 8. The regression of normal group model no. 2.

Regression Neural Network model, we trained the models with their dataset in that range. The three best performed model in each group of blood glucose were exported to verify and test with testing dataset. The results indicate Regression normal model no. 2, which show in Fig. 8, Regression Pre-diabetes model no. 3, which show in Fig. 9 and Regression Diabetes model no. 3, which show in Fig. 10 is the most suitable and effective models for normal, pre-diabetes and diabetes group respectively. Because of having low MSE and R values are nearest to one.

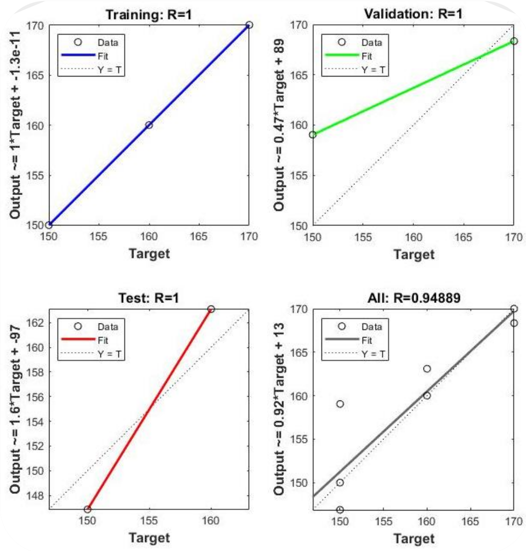

Figure 9. The regression of pre-diabetes group model no. 3.

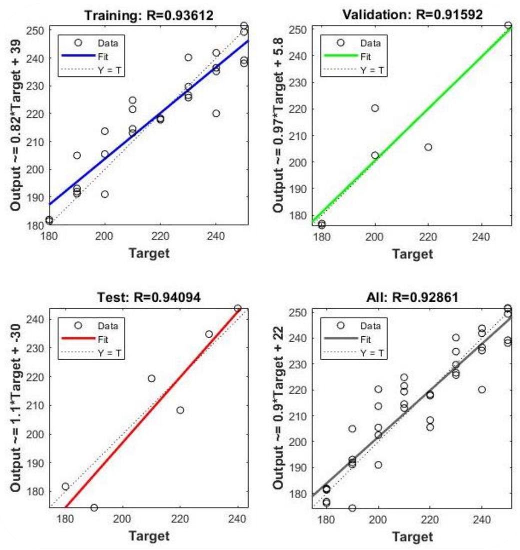

Figure 10. The regression of diabetes group model no. 3.

V. Discussion

Although the results are in an acceptable performance, but in this research still has many weakness points because of the number of datasets for training process is not enough to train the network until it gives the best performance. The various values train network provide more accurate network can predict. Also, this research is studied only based on the in vitro experiment, so it is not completely accurate enough when testing with human. Due to the condition of human body is quite complicate although we have tried to control many variables while doing the experiment. However, the in vivo, the biological experimental that can be done in living things, has the limitation of legal that is not allowed. Since the limitation of time we have so the studied of this research would be only the prototype of this research field that could be improved or applied with the other innovations.

VI. Conclusion

In this research, a large in vitro data set of glucose absorbance in concentration between 100 mg/dL to 250 mg/dL were collected to be the training dataset for the artificial neural network algorithm. The machine learned from the training data set to recognize and try to improve algorithm of network to reach the desire performance.

After feature extraction to select the suitable mother wavelet, the result has point out that Haar mother wavelet is the most suitable mother wavelet in this research which gives the least mean square error for most of the sample signals. Then the Haar mother wavelet was applied to the next step to extract the eigenvalues. After that the 9 features from previous part is selected for classification artificial neural network model training by means of 20 hidden layers and it gives approximate 16.67% of error. As well as, the regression artificial neural network model gives an accuracy of blood glucose in term of regression value approximate to 0.9534.

As the results, we can conclude that this prototype device can be used to measure the glucose concentration which the predicted values from selected models are in acceptable range. At the same time, it still can’t show the best performance because of some limitations. Moreover, this study is only base on the primary prototype device that left for further development.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Sarinporn Visitsattapongse is responsible for research design, research summary and recommendation. Chuchart Pintavirooj and Baorong Ni are recommendation. Jindapa Nampeng and Yanisa Samona are data analysis and research experiment.

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