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Blood Glucose Measurement and Analysis: Methodology

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Abstract**—**There is numerous non-invasive blood glucose measurement technique developed by researchers, and near infrared (NIR) is the potential technique nowadays. However, there are some disagreements on the optimal wavelength range that is suitable to be used as the reference of the glucose substance in the blood. This paper focuses on the experimental data collection technique and also the analysis method used to analyze the data gained from the experiment. The selection of suitable linear and non-linear model structure is essential in prediction system, as the system developed need to be conceivably accurate.

Keywords**—**Invasive, linear, near-infrared (Nir), non-invasive, non-linear, prediction system.

I. Introduction

STATISTICALLY, according to the World Health Organization (WHO) [1], there are over 300 million people who suffered from diabetes with over 3 million died from the complication of it. Maintaining the glucose level is very important for the diabetes patients thus the frequent monitoring is very important. There are patients who refuse the blood examination simply because terrified of needles and blood. Thus, the non-invasive blood glucose measurement is the optional solution to encourage the blood examination among the potential patients. The clinical range of glucose level frequently stated as [2]:

$$\text{Diabetic} = \begin{cases} 0, & 4mmol/L \leq BGL \leq 7mmol/L \\ 1, & BGL \leq 7mmol/L \end{cases} \quad (1)$$

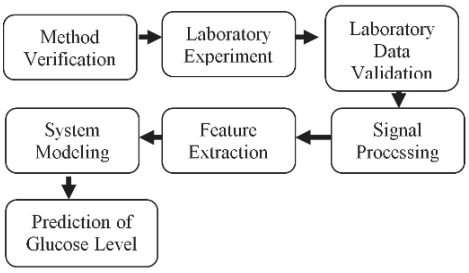

Fig. 1 The methodology chart of the blood glucose measurement system

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The research in non-invasive methods have currently gained wide attention and among the methods that were investigated including photometry [3], bio-impedance [3]-[5], thermography [6], ultrasonic sensor [7] and much more. Fig. 1 shows the methodology chart of the blood glucose measurement system that will be implemented in this study.

The chart shows the process from the method verification of the laboratory experiment until the implementation of the system identification models for the prediction of the glucose concentration in blood.

II. Data Collection

A. Subject Preparation

The raw data was collected from the diabetic patients in Outpatient Department (OPD), Hospital Universiti Sains Malaysia (HUSM) Kubang Kerian, Kelantan. Fig. 2 shows the frequently used phrases in preparing the data samples from the subjects with diabetes and non-diabetes [2], [8], [9].

Subjects are divided into 3 groups which are the patients with diabetes, non-diabetes personal and also control group (without an earlier diagnosis). The data collected from diabetes and non-diabetes personal will served as the data input for the system while the measurement from the control group served as the testing data for the system. The data collected using both invasive (the existing practiced method) and non-invasive distributed in Clark Error Grid Analysis (CEGA) graph as the correlation testing [9], [10] as in Fig. 3.

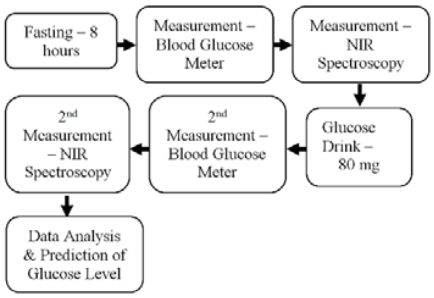


Fig. 2 The measurement procedures using both invasive and non-invasive technique

Following shows the correlation region between the reference data and the collected data from the new method (as in this research is the NIR measurement data) [8].

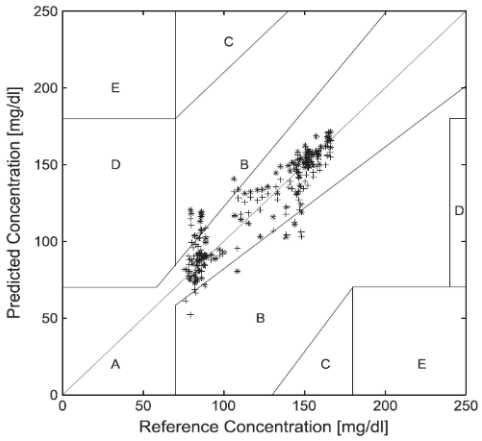


Fig. 3 Clarke Error Grid Analysis

Region A. within 20% of the reference sensor
Region B. outside of 20% but would not lead to inappropriate treatment
Region C. leading to unnecessary treatment
Region D. indicating a potentially dangerous failure to detect hypoglycemia or hyperglycemia
Region E. confuse treatment of hypoglycemia for hyperglycemia and vice-versa.

B. NIR Spectroscopy

NIR spectroscopy is proven to be useful in various biotechnology and characteristic applications [11], [12]. This study investigates the usefulness of the NIR as a medium in predicting the potential wavelength range that consists the information of the glucose substance in the blood. The experimental setup for the measurement of NIR is as in Fig. 4.

C. Other Substances Influence

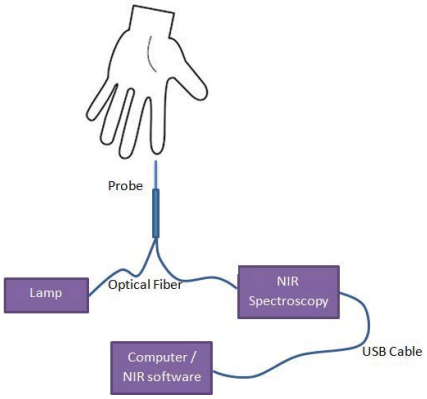
The wavelength range of the NIR that used in this study starts off from 700nm until 2300nm. This wavelength range is selected as it has more valuable information. However; as the range gets wider, there is more complicated information. For example, other substance peaks appeared along the glucose peak, such as water, lactose, oxygen and fat, which could affect the result.

Glucose is known to have more than one absorption point in NIR wavelength regions, and these peaks can help to overcome the difficulty in determining the glucose reading. The suitable range of the spectral region needed as to indicate the presence of the glucose in blood [13], [14].

Following Fig. 5 shows the wavelength range of the NIR and several components that appeared in the region.

D. Pilot Test

Fig. 6 shows the example of the raw data taken using the NIR Spectroscopy from several diabetic patients in Outpatient Department (OPD), Hospital Universiti Sains Malaysia (HUSM) Kubang Kerian, Kelantan. The data is in the absorbance waveform phase.



(a)

(b)

Fig. 4 (a) The illustration of the NIR measurement setup, (b) the actual NIR Spectroscopy setup

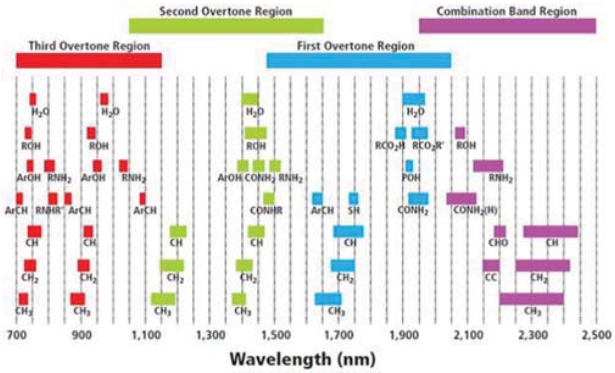


Fig. 5 The spectral region of near infrared

III. Data Analysis

The linear and non-linear both will be used as a model in the prediction system of the glucose concentration in blood. This process started with model structure selection, model estimation, and model validation. This will contribute to a better system in predicting the glucose concentration in blood using the non-invasive technique.

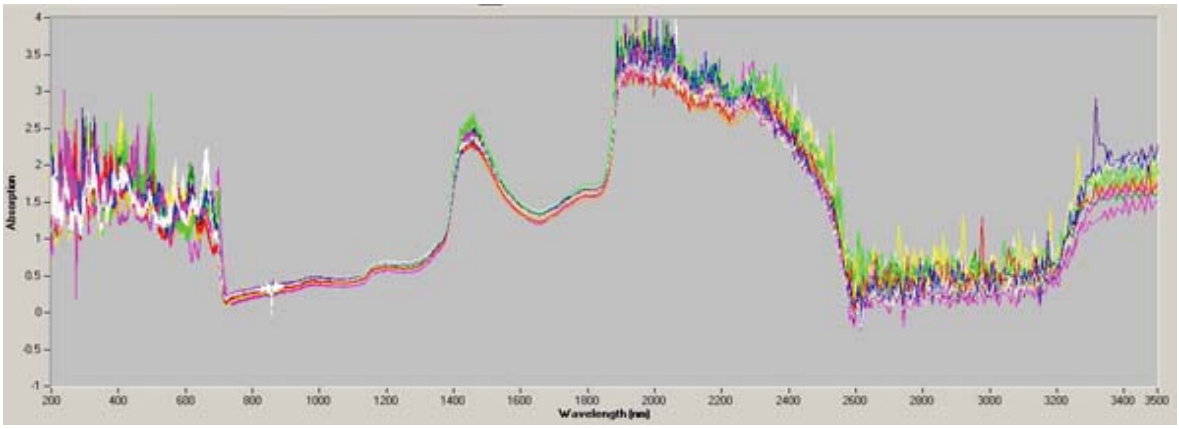


Fig. 6 The example of raw data using NIR Spectroscopy

A. Linear Model

The linear models that will be implemented in this research are:

i. autoregressive (AR) model that defined as:

$$G(z,p) = 1,\ H(z,p) = \frac{1}{A(z)} \quad (2)$$

where $A(z) = 1+a_1 z^{-1}+\ldots+a_{n_a} z^{-n_a}$

ii. autoregressive with exogenous input (ARX) model that defined as:

$$G(z,p) = \frac{B(z)}{A(z)},\ H(z,p) = \frac{1}{A(z)} \quad (3)$$

where A(z) is the same and $B(z)=b_1 z^{-1}+\ldots+b_{n_b} z^{-n_b}$

iii. autoregressive moving average with exogenous (ARMAX) model that defined as:

$$G(z,p) = \frac{B(z)}{A(z)},\ H(z,p) = \frac{C(z)}{A(z)} \quad (4)$$

where A(z) and B(z) are the same and $C(z) =1+ c_1 z^{-1}+\ldots+c_{n_c} z^{-n_c}$

The result will be compared to determine the model with more accurate prediction.

B. Non-Linear Model

The non-linear system known to be the most accurate system in the world where most of the system exist in the real application are based on non-linear. The non-linear models that will be implemented in this research are:

i. non-linear autoregressive (NAR) model that can be defined as:

$$\hat{y}(t) = F[y(t-1),\ldots,y(t-n_y),u(t)] \quad (5)$$

ii. nonlinear autoregressive with exogenous input (NARX) model that can be defined as:

$$\hat{y}(t) = F[y(t-1),\ldots,y(t-n_y),u(t-1),\ldots,u(t-k-n_u)] \quad (6)$$

iii. non-linear autoregressive moving average with exogenous (NARMAX) model that can be defined as:

$$\hat{y}(t) = F[y(t-1),\ldots,y(t-n_y),u(t-1),\ldots,u(t-k-n_u)]+\varepsilon(t-1),\ldots \varepsilon(t-n_\varepsilon)+ \varepsilon(t) \quad (7)$$

The result from both linear and non-linear models will be analyzed as to determine the most suitable model for the blood glucose concentration prediction system. The accuracy of each model is important, as it will determine the efficiency of the non-invasive method used in the actual practice.

IV. Conclusion

This research is concentrating in optimizing the usefulness of NIR in collecting the data of the glucose concentration in blood by using the non-invasive technique. Besides, the main goals of the NIR experiment are to determine the suitable wavelength and peaks that represent the glucose substance in the blood. The peaks of the NIR are important as the wavelength also consist a lot of other components that might interfere with the glucose reading. The models of the identification system implement in predicting the glucose level using the data from the NIR experiment. This is to analyze the data using the most suitable model and contribute a better result of the system. The result of the research can contribute to the development of the new system identification in determining the glucose concentration in blood. As per current invasive method, the patients prick their fingers multiples times a day, which could contribute to calluses, sensitive fingers and much more. As for this proposed method, it is expected to be faster in processing time and providing much information as possible for the damage-control purpose.

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