Prediction of Blood Glucose Level Using Near Infrared Spectroscopy

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Introduction

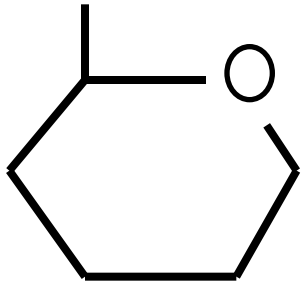
- World Health Organization (WHO) – over 300 millions people suffered from diabetes (over 3 million died from the complication)
- Maintaining the glucose level is very important. The clinical range:

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

0 = personal without diabetic
1 = possible diabetic patient

- 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.
- This research focusing on implementation of Near-Infrared (NIR) in measuring the blood glucose level.

- Glucose is an example of a carbohydrate which is commonly known as blood sugar or dextrose.
- Its chemical formula is $C_6H_{12}O_6$, and this empirical formula is shared by other structural sugars.
- In blood and cells of plants and animals - most of the glucose consists of molecules shaped into a ring.



Objectives

- To evaluate the usefulness of NIR spectrum in detecting the glucose level in blood.
- To analyse data using suitable model, both linear and non-linear model.
- To evaluate NIR potential as a non-invasive method from the performance of predictive model.

Project Scope

- **NIR Reflectance Spectroscopy** (900nm-2600nm) (Arcoptix):

- Instrument: Spectrometer, light source, and fiber optic,

- Software: ARCspectro FT Spectrometer

- **Subject Recruitment:**

- Case Subject - Diabetic Patient

- Non-diabetic Personal

- Control Subject - Personal without earlier diagnosis

- **Data Acquisition:**

- Spectral Data: NIR spectroscopy,

- Laboratory/Validation Data: Measurement from Blood Glucose Meter

- **Data Analysis:**

- Linear Prediction Model: ARX, ARMAX

- Non-linear Prediction Model: NARX, NARMAX

Previous Research

Research By:	Technique	
L. Ben Mohammadi, T. Klotzbuecher, S. Sigloch, K. Welzel, M. Göddel, T.R. Pieber, et al., In vivo evaluation of a chip based near infrared sensor for continuous glucose monitoring. (2014)	- Infrared	- chip-based NIR sensor combined with micro-dialysis, emitting at 1300, 1450 and 1550 nm. - 24 hours monitoring - The mean absolute relative error (MARE) applied as the baseline correction technique
H. Yoshinari, H. Ishizawa, M. Fukuda, S. Tokutake Non-invasive Self Monitoring of Blood Glucose System Using Near-infrared Spectroscopy. (2012)	- Infrared	- detect glucose in aqueous solution and the results were applied to the human body. - analysis - Partial Least Square Regression (PLSR)
A. Caduff, M. Mueller, A. Megej, F. Dewarrat, R.E. Suri, J. Klisic, et al., Characteristics of a multisensor system for non invasive glucose monitoring with external validation and prospective evaluation. (2011)	- Multisensory	- sense the dielectric characteristics of human skin tissues and the optical characteristics at 1 kHz to 100 MHz, 1 and 2 GHz - temperature and humidity variations, skin perfusion, sweating and movement.

K.A.U. Menon, D. Hemachandran, A.T. Kunnath Voltage intensity based non-invasive blood glucose monitoring. (2013)	- Infrared	- the scattering properties technique that has the direct effect on the glucose of human body. - NIR (max 980 nm) at fingertip - The mismatch in refractive index between scatters and their surrounding media was caused by a decrease in glucose concentration. - Fast Fourier Transform (FFT) analysis
S. Sivanandam, M. Anburajan, B. Venkatraman, M. Menaka, D. Sharath Estimation of blood glucose by non-invasive infrared thermography for diagnosis of type 2 diabetes: An alternative for blood sample extraction. (2013)	- Thermography	- determines the glycated haemoglobin (HbA1c) in blood using the measurement of the body temperature. - optimal regression model was achieved from the significant variables that correlated with the HbA1c - core body temperature decreases, body metabolism also decrease.

M. Anas, M. N., Syafirah, A., Norali, A. N. & Normahira Non-invasive blood glucose measurement Application of near infrared optical measurement. (2012)	- Infrared and Photodiode	- infrared emitter on fingertip and a photo-diode - glucose molecules in the blood determine the intensity of the received light, and the voltage measured. i. Normal non-fasting = 6.3 to 11.5 mol/L, voltage 1.4 V to 1.66 V. ii. Normal fasting = 4.7 to 5.5 mol/L, voltage 1.38 V to 1.61 V. - analysed using simple polynomial regression. For the data analysis process, the second order of the polynomial regression is used
Y. Zhou, C. Zheng, H. Cao, X. Li, J. Sha Measurement of hemoglobin in whole blood using a partial least squares regression model with selected second derivative near infrared transmission spectral signals. (2012)	- Infrared	- haemoglobin (Hb) concentration in - proving the usefulness of NIR in detecting haemoglobin in blood. - 1100 to 2498 nm - leave-one-out root-mean-squared error of cross validation (RMSECV), RMSEP and the squared correlation coefficient (R2)

Methodology

Diabetic Patients

Non Diabetic Patients & Control Group

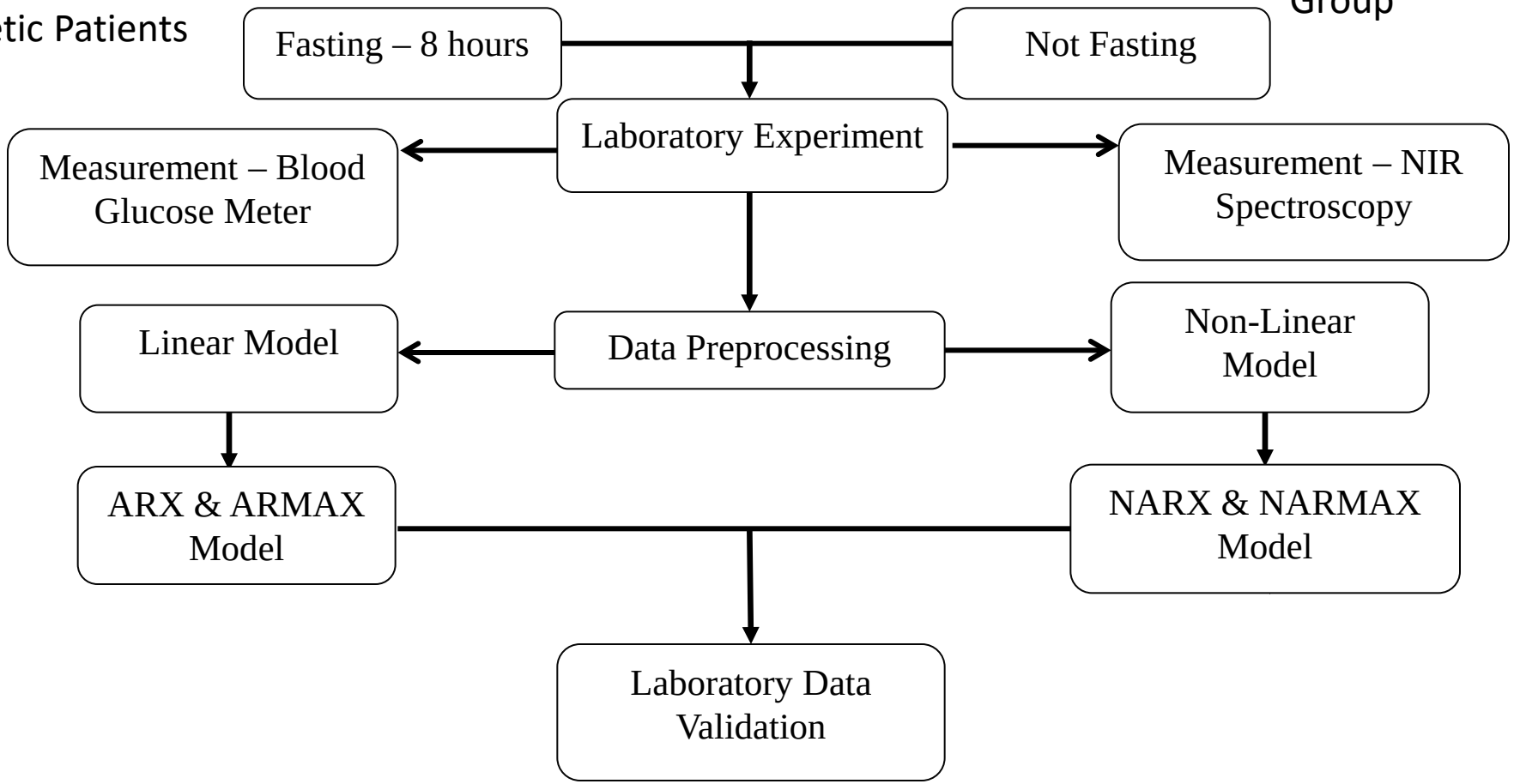


Fig. 1: The methodology chart of the blood glucose measurement

Data Collection (Laboratory Experiment)

- The raw data was collected from the diabetic patients in Outpatient Department (OPD), Hospital Universiti Sains Malaysia (HUSM) Kubang Kerian, Kelantan, Malaysia.
- Subjects are divided into 3 groups which are the **patients with diabetes**, **non-diabetes personal** and also **control group (without earlier diagnosis)**.
- The reference data measured using the clinical Blood Glucose Meter

- This study proposed the usefulness of the NIR in predicting the potential wavelength range that consist the information of the glucose substance in blood.

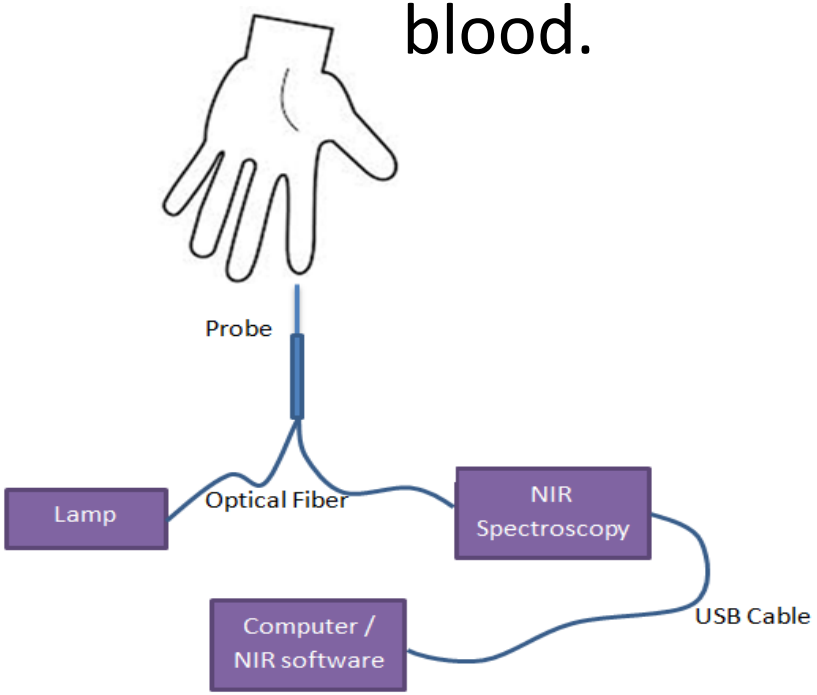


Fig. 2: (a) The illustration of the NIR measurement setup, (b) the actual NIR Spectroscopy setup

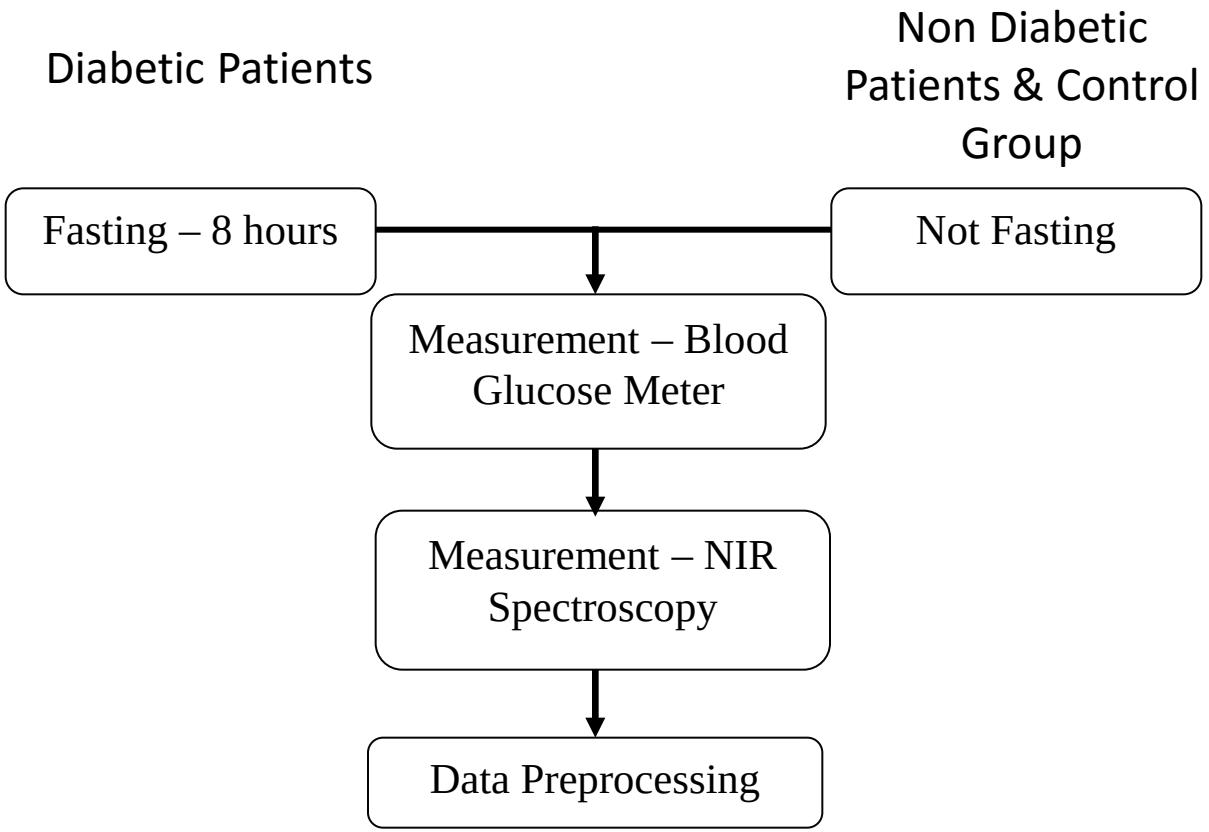


Fig. 3: The measurement procedures using both invasive and non-invasive technique

Signal Analysis & Feature Extraction

- The wavelength measured from 200nm – 3500nm.
- Nevertheless, information from 1000nm – 2000nm are investigated.
- The significant peaks that represent the glucose absorption points.

- 1440nm
- 1940nm

- Suitable features are extracted manually from the raw data taken using the NIR Spectroscopy.

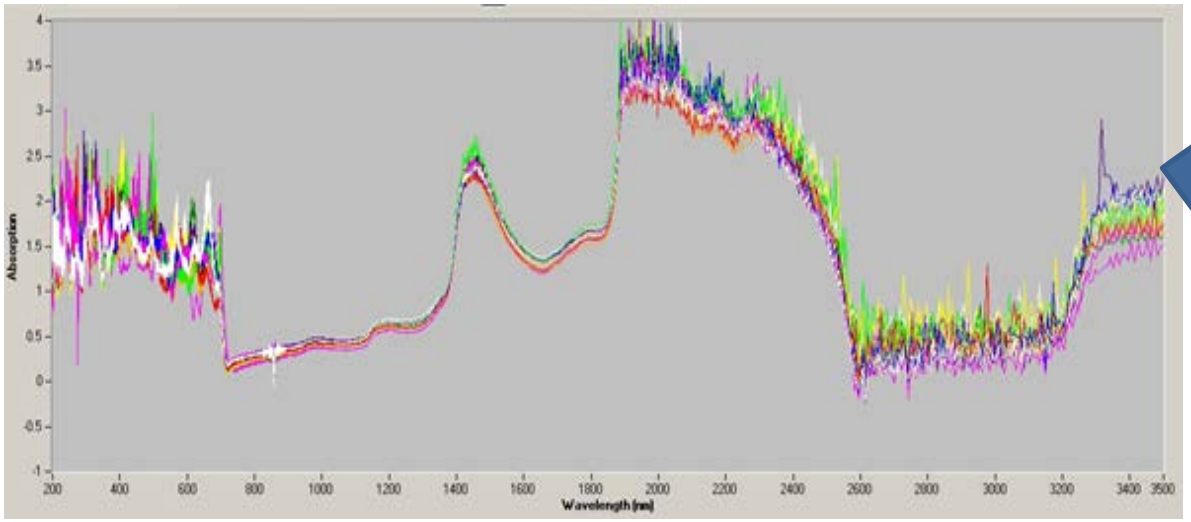


Fig. 4: The raw data from NIR Spectroscopy

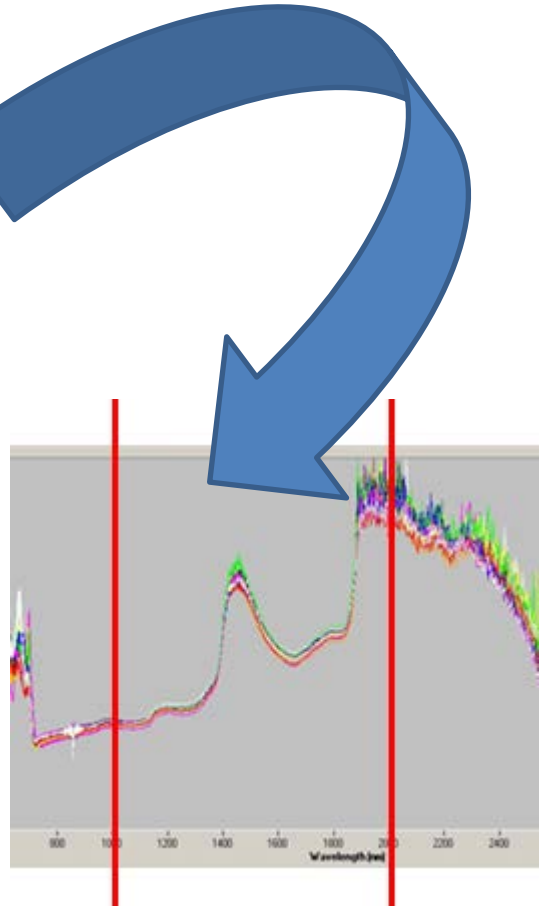


Fig. 5: The extracted raw data

Data Pre-processing

- Noise Filtering- To enhance the quality of the acquired data by eliminate or minimize the effect of unwanted signal.

- using the raw spectral data

- using zero derivative first polynomial order Savitzky-Golay Filter

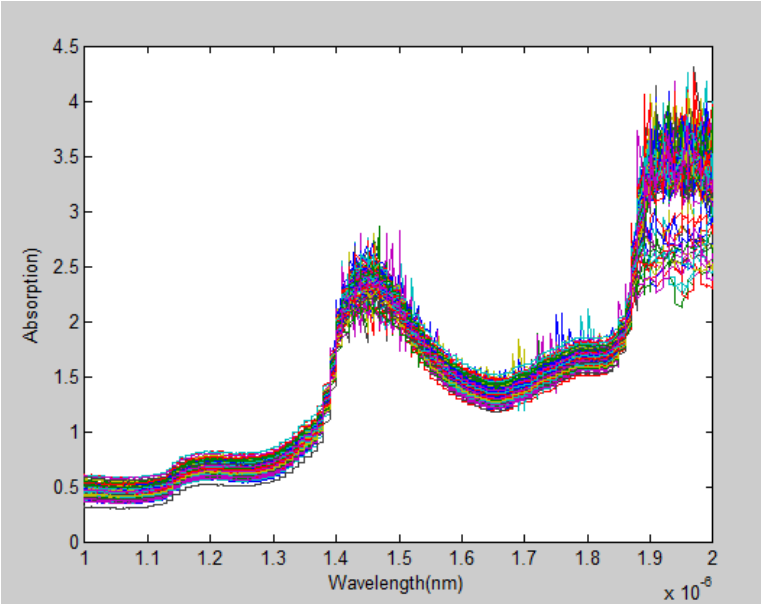


Fig. 6: Raw Signal data at fingertip

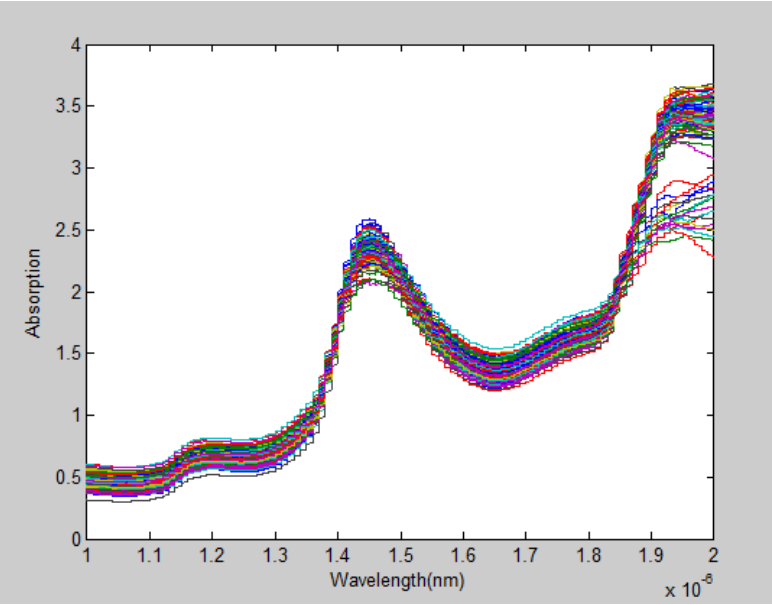


Fig. 7: Pre-processed Signal data at fingertip

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 contribute to a better system in predicting the glucose concentration in blood using the non-invasive technique.

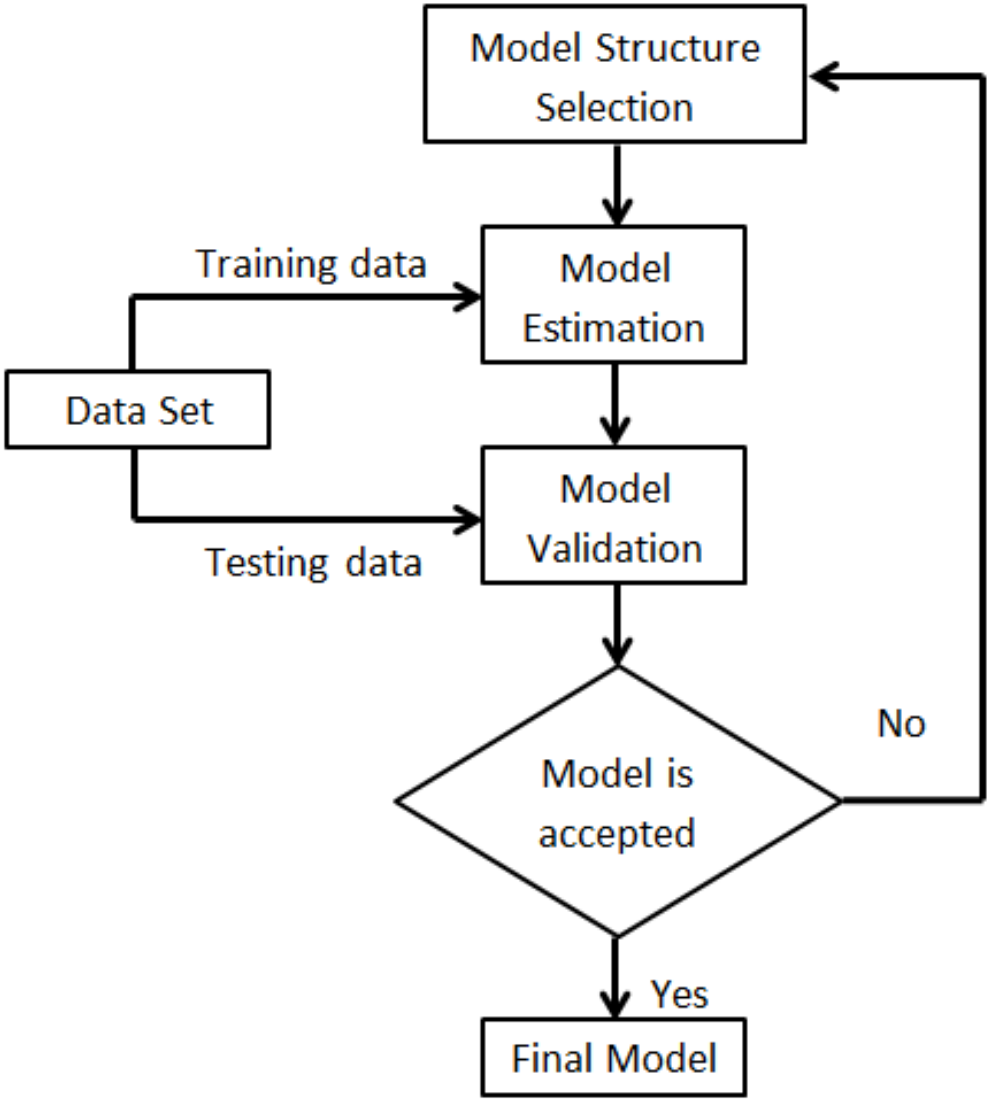


Fig. 7: Flowchart of data analysis

Model Structure Selection

- The system identification models that implemented in the research are:
- **Linear Model**

i. Autoregressive with Exogenous Input (ARX)

ii. Autoregressive Moving Average with Exogenous (ARMAX)

- **Non-Linear Model**

i. Non-Linear Autoregressive with Exogenous Input (NARX)

ii. Non-Linear Autoregressive Moving Average with Exogenous (NARMAX)

Model Prediction & Validation

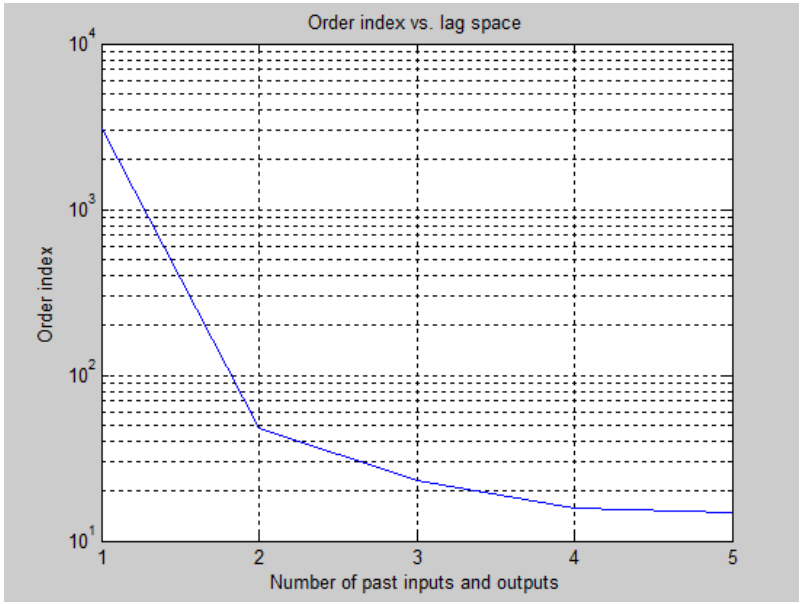
- Dataset contains 138 data from 3 groups divided for model estimation and validation
- 97 data set – prediction
- 41 data set – validation
- Regularization & Unregularization

Current Progress

- Model Order Selection:

- Lipschitz Function
- Akaike's Information Criterion (AIC) - future
- Akaike's Final Prediction Error (FPE) - future

NARX



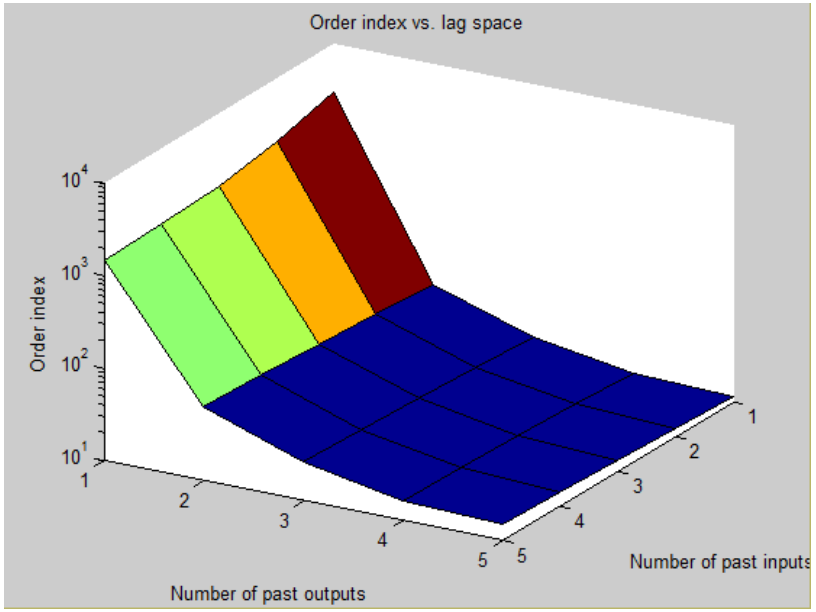
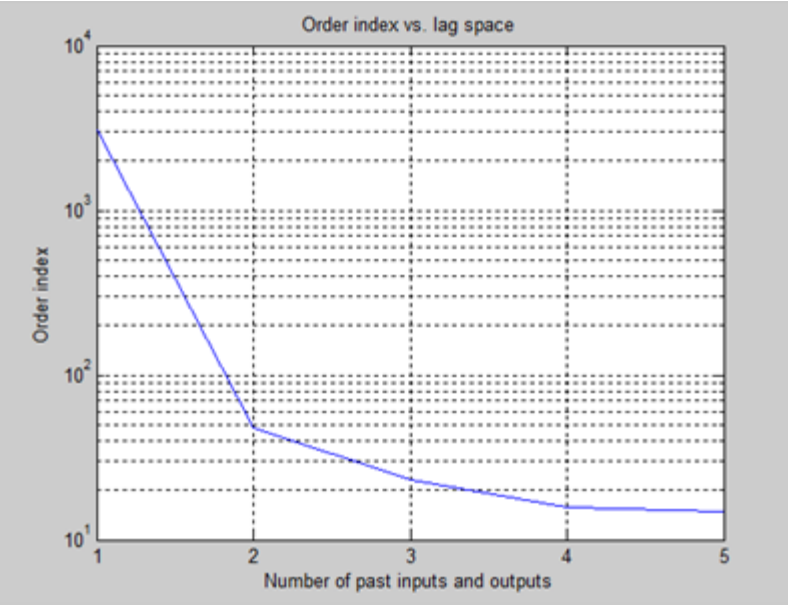


Fig. 8: The model order selection using Lipschitz Function for NARX

NARMAX



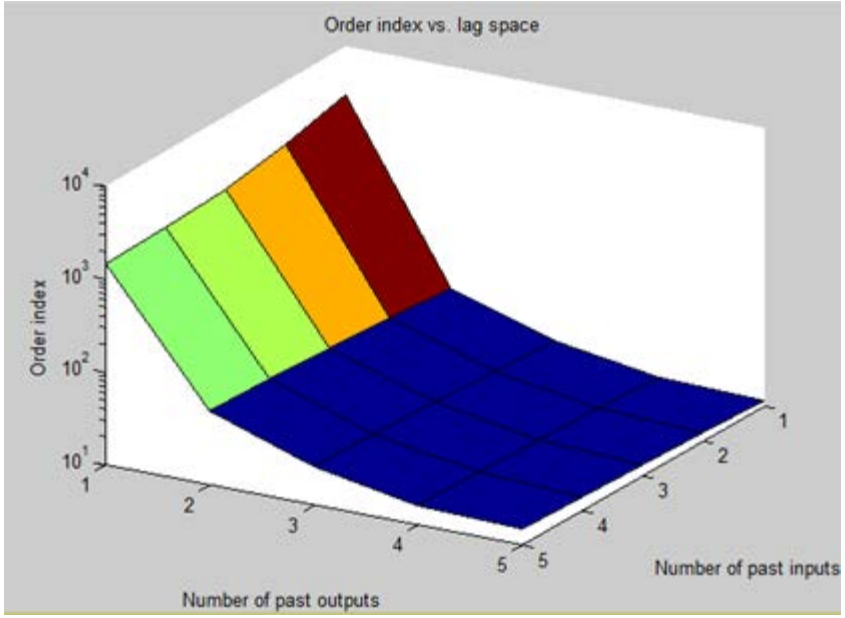


Fig. 9: The model order selection using Lipschitz Function for NARMAX

- NARX

	Lipschitz	FPE	AIC
Model Order	2	-	-
Max Iteration	100	-	-
Regularization	1e-3	-	-
NSSE	0.9		

- NARMAX

	Lipschitz	FPE	AIC
Model Order	2	-	-
Max Iteration	100	-	-
Regularization	2e-3		
NSSE	1.3		

NARX

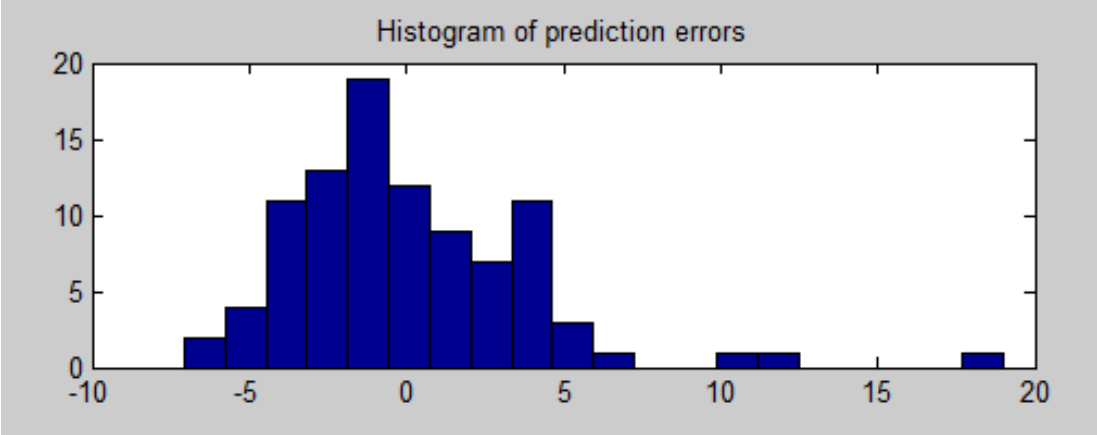


Fig. 10: Histogram of prediction error

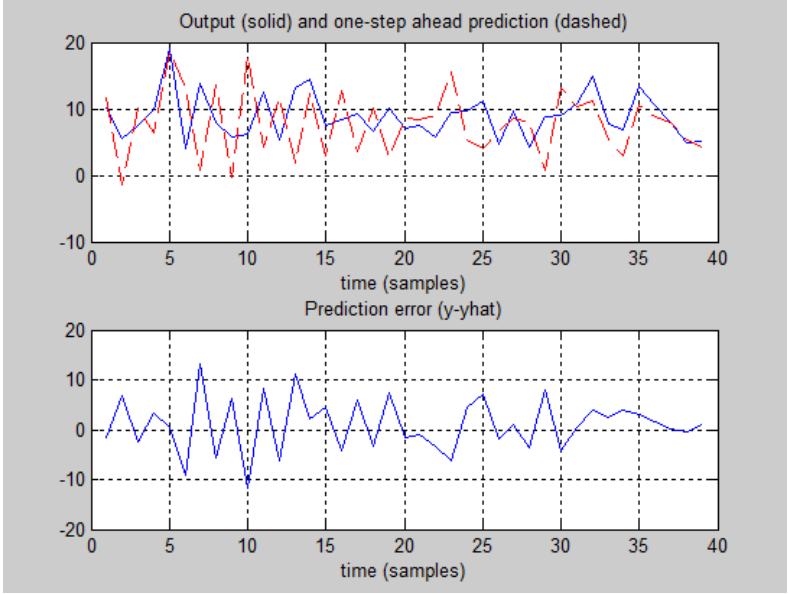


Fig. 11: (a) one-step-ahead prediction
(b) prediction error

NARMAX

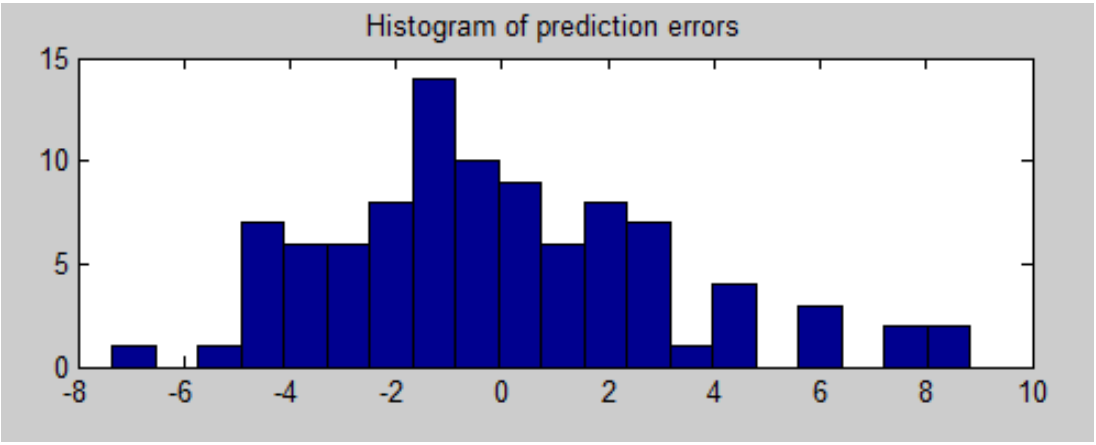


Fig. 12: Histogram of prediction error

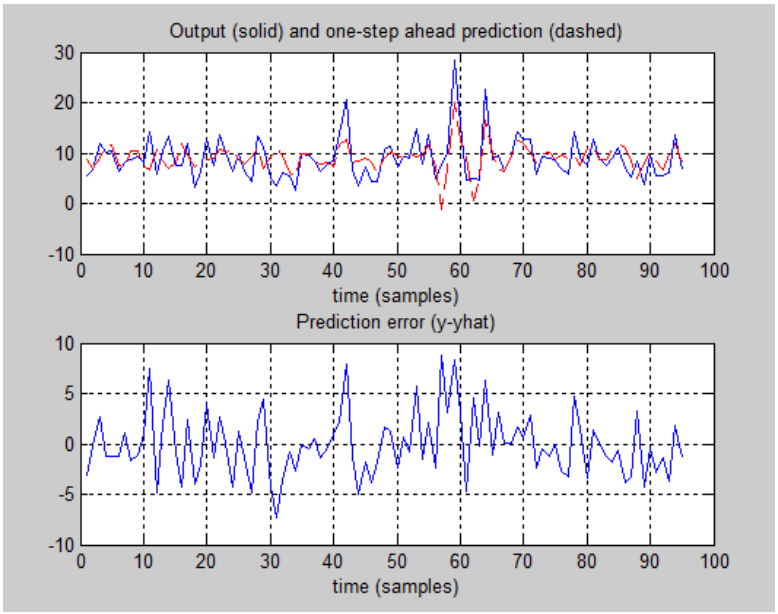


Fig. 13: (a) one-step-ahead prediction
(b) prediction error

- The system modelling using the NARX and NARMAX shows slightly unsatisfying result.
- Try the combination of various parameters
- The improvement needed on the data set.
- Noises may influence the result

Laboratory Data Validation

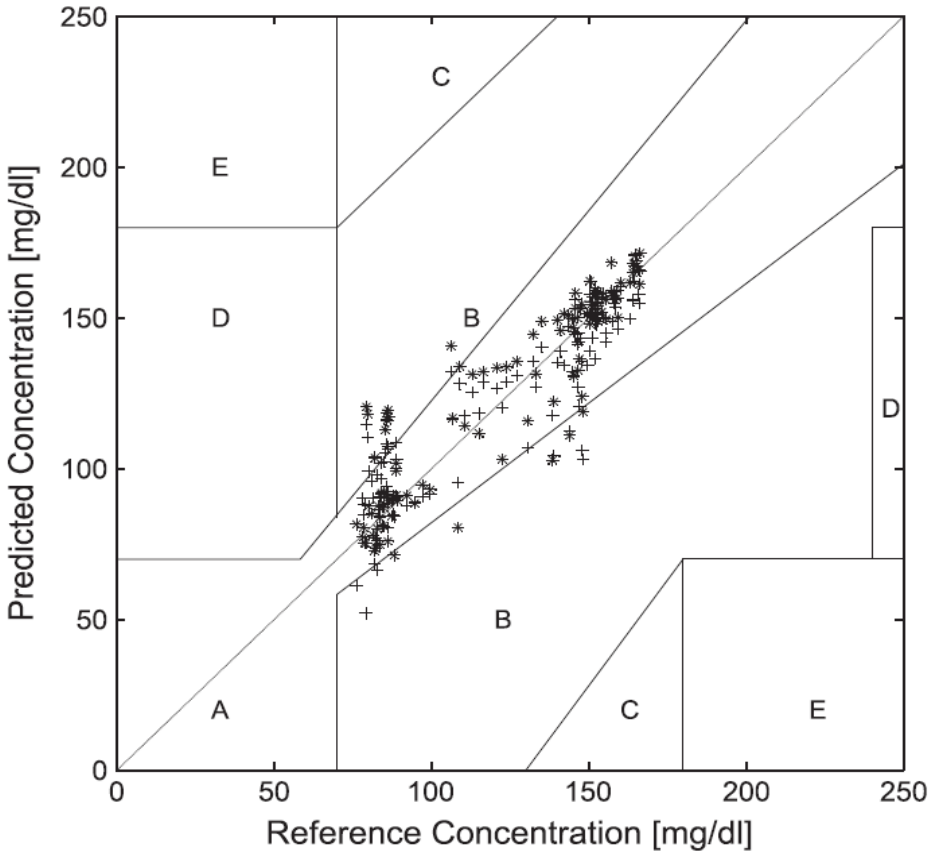


Fig. 14: Clarke Error Grid Analysis

- Data collected using both invasive (the existing practiced method) and non-invasive distributed in Clark Error Grid Analysis (CEGA) graph.
- Need to find correlation coefficient

- **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.

Conclusion

- Concentrating in optimizing the usefulness of NIR in collecting the data of the glucose concentration in blood.
- Determine the suitable wavelength and peaks.
- The peaks in wavelength also consist a lot of other components that might interfere with the glucose reading.

- Analyze the data using the most suitable model and contribute a better result for the system.
- The result of the research can contribute to development of the new system in determining the glucose concentration in blood.

Future Works

- Using only significant peaks from the wavelength as the input for model structure
- Using another technique for model order selection

- [1] E.M.A. A. Trabelsi, M. Boukadoum, C. Fayomi, Blood glucose sensor implant using NIR spectroscopy: Preliminary design study, in: Microelectron. (ICM), 2010 Int. Conf. On, Cairo, 2010: pp. 176–179.
- [2] W.H. Organization, Facts and figures about diabetes, (2014). http://www.who.int/diabetes/en/ (accessed January 01, 2014).
- [3] C.F. So, K.S. Choi, J.W.Y. Chung, T.K.S. Wong, An extension to the discriminant analysis of near-infrared spectra, Med. Eng. Phys. 35 (2013) 172–177. doi:10.1016/j.medengphy.2012.04.012.
- [4] L. Ben Mohammadi, T. Klotzbuecher, S. Sigloch, K. Welzel, M. Göddel, T.R. Pieber, et al., In vivo evaluation of a chip based near infrared sensor for continuous glucose monitoring., Biosens. Bioelectron. 53 (2014) 99–104. doi:10.1016/j.bios.2013.09.043.
- [5] S. Sivanandam, M. Anburajan, B. Venkatraman, M. Menaka, D. Sharath, Estimation of blood glucose by non-invasive infrared thermography for diagnosis of type 2 diabetes: An alternative for blood sample extraction, Mol. Cell. Endocrinol. 367 (2013) 57–63. doi:10.1016/j.mce.2012.12.017.
- [6] C. Review, S. Communication, G. Principles, World Medical Association Declaration of Helsinki. Ethical principles for medical research involving human subjects., Nurs. Ethics. 9 (2002) 105–109.
- [7] A. Caduff, M. Mueller, A. Megej, F. Dewarrat, R.E. Suri, J. Klisic, et al., Characteristics of a multisensor system for non invasive glucose monitoring with external validation and prospective evaluation, Biosens. Bioelectron. 26 (2011) 3794–3800. doi:10.1016/j.bios.2011.02.034.
- [8] P. Li, G. Du, W. Cai, X. Shao, Journal of Pharmaceutical and Biomedical Analysis Rapid and nondestructive analysis of pharmaceutical products using near-infrared diffuse reflectance spectroscopy, J. Pharm. Biomed. Anal. 70 (2012) 288–294. doi:10.1016/j.jpba.2012.07.013.
- [9] Y. Hu, X. Jiang, L. Zhang, J. Fan, W. Wu, Construction of near-infrared photonic crystal glucose-sensing materials for ratiometric sensing of glucose in tears, Biosens. Bioelectron. 48 (2013) 94–99. doi:10.1016/j.bios.2013.03.082.

- [10] Q.-B. Li, L.-N. Li, G.-J. Zhang, A nonlinear model for calibration of blood glucose noninvasive measurement using near infrared spectroscopy, Infrared Phys. Technol. 53 (2010) 410–417. doi:10.1016/j.infrared.2010.07.012.
- [11] I. APPLICATION, Integrity Application, (2013). http://www.integrity-app.com/ (accessed January 01, 2014).
- [12] A. Caduff, M.S. Talary, M. Mueller, F. Dewarrat, J. Klisic, M. Donath, et al., Non-invasive glucose monitoring in patients with Type 1 diabetes: A Multisensor system combining sensors for dielectric and optical characterisation of skin, Biosens. Bioelectron. 24 (2009) 2778–2784. doi:10.1016/j.bios.2009.02.001.
- [13] Y. Miyauchi, T. Horiguchi, H. Ishizawa, S. i. Tezuka, H. Hara, Basis examination for development of noninvasive blood glucose measuring instrument by near-infrared confocal optical system, SICE Annu. Conf. 2010, Proc. (2010) 3427–3429.
- [14] Y. Miyauchi, T. Horiguchi, H. Ishizawa, S. i. Tezuka, H. Hara, Blood glucose level measurement by confocal reflection photodetection system, SICE Annu. Conf. (SICE), 2011 Proc. (2011) 2686–2689.
- [15] M. Anas, M. N., Syafirah, A., Norali, A. N. & Normahira, Non-invasive blood glucose measurement Application of near infrared optical measurement, in: Sustain. Util. Dev. Eng. Technol. (STUDENT), 2012 IEEE Conf., 2012: pp. 258–261.
- [16] E. Nakamachi, Development of automatic operated blood sampling system for portable type Self-Monitoring Blood Glucose device, 2010 Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBC'10. (2010) 335–338. doi:10.1109/IEMBS.2010.5627675.
- [17] C.F. Amaral, M. Brischwein, B. Wolf, Multiparameter techniques for non-invasive measurement of blood glucose, Sensors Actuators, B Chem. 140 (2009) 12–16. doi:10.1016/j.snb.2009.04.023.
- [18] a. Caduff, E. Hirt, Y. Feldman, Z. Ali, L. Heinemann, First human experiments with a novel non-invasive, non-optical continuous glucose monitoring system, Biosens. Bioelectron. 19 (2003) 209–217. doi:10.1016/S0956-5663(03)00196-9.

- [19] a. Caduff, F. Dewarrat, M. Talary, G. Stalder, L. Heinemann, Y. Feldman, Non-invasive glucose monitoring in patients with diabetes: A novel system based on impedance spectroscopy, Biosens. Bioelectron. 22 (2006) 598–604. doi:10.1016/j.bios.2006.01.031.
- [20] K.A.U. Menon, D. Hemachandran, A.T. Kunnath, Voltage intensity based non-invasive blood glucose monitoring, Comput. Commun. Netw. Technol. (ICCCNT),2013 Fourth Int. Conf. (2013) 1–5. doi:10.1109/ICCCNT.2013.6726720.
- [21] C. MEDICAL, Cnoga's Combo Glucometer, (2013). http://cnogacare.co/ (accessed January 01, 2015).
- [22] F. Khan, J.C. Pickup, Near-infrared fluorescence glucose sensing based on glucose/galactose-binding protein coupled to 651-Blue Oxazine, Biochem. Biophys. Res. Commun. 438 (2013) 488–492. doi:10.1016/j.bbrc.2013.07.111.
- [23] H. Yoshinari, H. Ishizawa, M. Fukuda, S. Tokutake, Non-invasive Self Monitoring of Blood Glucose System Using Near-infrared Spectroscopy, (2012) 1852–1854.
- [24] A.C.D.O. Neves, A.A. de Araújo, B.L. Silva, P. Valderrama, P.H. Março, K.M.G. de Lima, Near infrared spectroscopy and multivariate calibration for simultaneous determination of glucose, triglycerides and high-density lipoprotein in animal plasma, J. Pharm. Biomed. Anal. 66 (2012) 252–257. doi:10.1016/j.jpba.2012.03.023.
- [25] Y. Zhou, C. Zheng, H. Cao, X. Li, J. Sha, Measurement of hemoglobin in whole blood using a partial least squares regression model with selected second derivative near infrared transmission spectral signals, Biochem. Biophys. Res. Commun. 420 (2012) 205–209. doi:10.1016/j.bbrc.2012.02.144.
- [26] M. Pleitez, H. Von Lilienfeld-Toal, W. Mäntele, Infrared spectroscopic analysis of human interstitial fluid in vitro and in vivo using FT-IR spectroscopy and pulsed quantum cascade lasers (QCL): Establishing a new approach to non invasive glucose measurement, Spectrochim. Acta - Part A Mol. Biomol. Spectrosc. 85 (2012) 61–65. doi:10.1016/j.saa.2011.09.007.
- [27] K.E. Kramer, G.W. Small, Robust absorbance computations in the analysis of glucose by near-infrared spectroscopy, Vib. Spectrosc. 43 (2007) 440–446. doi:10.1016/j.vibspec.2006.05.025.

- [28] P. Bhandare, Y. Mendelson, E. Stohr, R. a. Peura, Glucose determination in simulated blood serum solutions by Fourier transform infrared spectroscopy: investigation of spectral interferences, Vib. Spectrosc. 6 (1994) 363–378. doi:10.1016/0924-2031(93)E0059-B.
- [29] J.J. Burmeister, M. a Arnold, Evaluation of measurement sites for noninvasive blood glucose sensing with near-infrared transmission spectroscopy., Clin. Chem. 45 (1999) 1621–1627.
- [30] K. Maruo, M. Tsurugi, T. Ota, H. Arimoto, Y. Yamada, M. Tamura, et al., Noninvasive blood glucose assay using a newly developed near-infrared system, IEEE J. Sel. Top. Quantum Electron. 9 (2003) 322–330. doi:10.1109/JSTQE.2003.811283.
- [31] B. Liebmann, a. Friedl, K. Varmuza, Determination of glucose and ethanol in bioethanol production by near infrared spectroscopy and chemometrics, Anal. Chim. Acta. 642 (2009) 171–178. doi:10.1016/j.aca.2008.10.069.
- [32] G.G. Guilbault, G. Palleschi, G. Lubrano, Non-invasive biosensors in clinical analysis, Biosens. Bioelectron. 10 (1995) 379–392. doi:10.1016/0956-5663(95)96856-T.
- [33] J.L. Pezzaniti, T.W. Jeng, L. McDowell, G.M. Oosta, Preliminary investigation of near-infrared spectroscopic measurements of urea, creatinine, glucose, protein, and ketone in urine, Clin. Biochem. 34 (2001) 239–246. doi:10.1016/S0009-9120(01)00198-9.
- [34] Z.-M. Chuah, R. Paramesran, K. Thambiratnam, S.-C. Poh, A two-level partial least squares system for non-invasive blood glucose concentration prediction, Chemom. Intell. Lab. Syst. 104 (2010) 347–351. doi:10.1016/j.chemolab.2010.08.015.
- [35] I. Vályi-Nagy, K.J. Kaffka, J.M. Jákó, E. Gönczöl, G. Domján, Application of near infrared spectroscopy to the determination of haemoglobin., Clin. Chim. Acta. 264 (1997) 117–125.
- [36] S. Wold, H. Antti, F. Lindgren, J. Öhman, Orthogonal signal correction of near-infrared spectra, Chemom. Intell. Lab. Syst. 44 (1998) 175–185. doi:10.1016/S0169-7439(98)00109-9.

- [37] S.J. Yeh, C.F. Hanna, O.S. Khalil, Monitoring blood glucose changes in cutaneous tissue by temperature-modulated localized reflectance measurements, Clin. Chem. 49 (2003) 924–934. doi:10.1373/49.6.924.
- [38] O.S. Abdalsalam, A. k. M. Osman, R.M. Abd-Alhadi, S.D. Alshmaa, Design of simple noninvasive glucose measuring device, Comput. Electr. Electron. Eng. (ICCEEE), 2013 Int. Conf. (2013) 216–219. doi:10.1109/ICCEEE.2013.6633935.
- [39] J. Tenhunen, H. Kopola, R. Myllyla, Non-invasive glucose measuremnt based on selective near infrared absorption; requirement on instrumentation and spectral range, Measurement. 24 (1998) 173–177.
- [40] M. Mueller, M. Grunze, E.H. Leiter, P.C. Reifsnyder, U. Klueh, D. Kreutzer, Non-invasive glucose measurements in mice using mid-infrared emission spectroscopy, Sensors Actuators, B Chem. 142 (2009) 502–508. doi:10.1016/j.snb.2009.08.048.
- [41] B. Wan, G.W. Small, Wavelet analysis used for spectral background removal in the determination of glucose from near-infrared single-beam spectra, Anal. Chim. Acta. 681 (2010) 63–70. doi:10.1016/j.aca.2010.09.022.
- [42] N. Sorol, E. Arancibia, S. a. Bortolato, A.C. Olivieri, Visible/near infrared-partial least-squares analysis of Brix in sugar cane juice. A test field for variable selection methods, Chemom. Intell. Lab. Syst. 102 (2010) 100–109. doi:10.1016/j.chemolab.2010.04.009.
- [43] I. Delfino, C. Camerlingo, M. Portaccio, B. Della Ventura, L. Mita, D.G. Mita, et al., Visible micro-Raman spectroscopy for determining glucose content in beverage industry, Food Chem. 127 (2011) 735–742. doi:http://dx.doi.org/10.1016/j.foodchem.2011.01.007.
- [44] A. Rae, R. Stosch, P. Klapetek, A.R. Hight Walker, D. Roy, State of the art Raman techniques for biological applications, Methods. 68 (2014) 338–347. doi:http://dx.doi.org/10.1016/j.ymeth.2014.02.035.
- [45] a J. Berger, I. Itzkan, M.S. Feld, Feasibility of measuring blood glucose concentration by near-infrared Raman spectroscopy., Spectrochim. Acta. A. Mol. Biomol. Spectrosc. 53A (1997) 287–292. doi:10.1016/S1386-1425(96)01779-9.

- [46] G. Déléris, C. Petibois, Applications of FT-IR spectrometry to plasma contents analysis and monitoring, Vib. Spectrosc. 32 (2003) 129–136. doi:10.1016/S0924-2031(03)00053-5.
- [47] E. Monte-Moreno, Non-invasive estimate of blood glucose and blood pressure from a photoplethysmograph by means of machine learning techniques, Artif. Intell. Med. 53 (2011) 127–138. doi:10.1016/j.artmed.2011.05.001.
- [48] W.L. Clarke, D. Cox, L. a Gonder-Frederick, W. Carter, S.L. Pohl, Evaluating clnical accuracy of systems for self-monitoring of blood glucose, Diabetes Care. 10 (1987) 622–628.
- [49] A. Al-Mbaideen, M. Benaissa, Determination of glucose concentration from NIR spectra using independent component regression, Chemom. Intell. Lab. Syst. 105 (2011) 131–135. doi:10.1016/j.chemolab.2010.11.008.
- [50] S. Kasemsumran, Y.P. Du, K. Maruo, Y. Ozaki, Selective removal of interference signals for near-infrared spectra of biomedical samples by using region orthogonal signal correction, Anal. Chim. Acta. 526 (2004) 193–202. doi:10.1016/j.aca.2004.09.047.
- [51] S. Kasemsumran, Y.P. Du, K. Murayama, M. Huehne, Y. Ozaki, Near-infrared spectroscopic determination of human serum albumin, γ-globulin, and glucose in a control serum solution with searching combination moving window partial least squares, Anal. Chim. Acta. 512 (2004) 223–230. doi:10.1016/j.aca.2004.02.045.
- [52] D. Perez-Guaita, J. Kuligowski, G. Quintás, S. Garrigues, M.D. La Guardia, Modified locally weighted-Partial least squares regression improving clinical predictions from infrared spectra of human serum samples, Talanta. 107 (2013) 368–375. doi:10.1016/j.talanta.2013.01.035.
- [53] M. Zhang, S. Zhang, J. Iqbal, Key wavelengths selection from near infrared spectra using Monte Carlo sampling-recursive partial least squares, Chemom. Intell. Lab. Syst. 128 (2013) 17–24. doi:10.1016/j.chemolab.2013.07.009.
- [54] Y. Bi, Q. Xie, S. Peng, L. Tang, Y. Hu, J. Tan, et al., Dual stacked partial least squares for analysis of near-infrared spectra, Anal. Chim. Acta. 792 (2013) 19–27. doi:10.1016/j.aca.2013.07.008.

- [55] F. Allegrini, A.C. Olivieri, A new and efficient variable selection algorithm based on ant colony optimization. Applications to near infrared spectroscopy/partial least-squares analysis, Anal. Chim. Acta. 699 (2011) 18–25. doi:10.1016/j.aca.2011.04.061.
- [56] M. Jing, W. Cai, X. Shao, Multiblock partial least squares regression based on wavelet transform for quantitative analysis of near infrared spectra, Chemom. Intell. Lab. Syst. 100 (2010) 22–27. doi:10.1016/j.chemolab.2009.09.006.
- [57] X. Shao, X. Bian, W. Cai, An improved boosting partial least squares method for near-infrared spectroscopic quantitative analysis, Anal. Chim. Acta. 666 (2010) 32–37. doi:10.1016/j.aca.2010.03.036.
- [58] Q. Ding, G.W. Small, M. a. Arnold, Evaluation of nonlinear model building strategies for the determination of glucose in biological matrices by near-infrared spectroscopy, Anal. Chim. Acta. 384 (1999) 333–343. doi:10.1016/S0003-2670(98)00779-X.
- [59] G. Reich, Near-infrared spectroscopy and imaging: Basic principles and pharmaceutical applications, Adv. Drug Deliv. Rev. 57 (2005) 1109–1143. doi:10.1016/j.addr.2005.01.020.
- [60] Z. Xiaobo, Z. Jiewen, M.J.W. Povey, M. Holmes, M. Hanpin, Variables selection methods in near-infrared spectroscopy, Anal. Chim. Acta. 667 (2010) 14–32. doi:10.1016/j.aca.2010.03.048.
- [61] N. Kang, S. Kasemsumran, Y.A. Woo, H.J. Kim, Y. Ozaki, Optimization of informative spectral regions for the quantification of cholesterol, glucose and urea in control serum solutions using searching combination moving window partial least squares regression method with near infrared spectroscopy, Chemom. Intell. Lab. Syst. 82 (2006) 90–96. doi:10.1016/j.chemolab.2005.08.015.
- [62] D. Abookasis, J.J. Workman, Application of spectra cross-correlation for Type II outliers screening during multivariate near-infrared spectroscopic analysis of whole blood, Chemom. Intell. Lab. Syst. 107 (2011) 303–311. doi:http://dx.doi.org/10.1016/j.chemolab.2011.04.015.

- [63] J.L. Godoy, J.R. Vega, J.L. Marchetti, Chemometrics and Intelligent Laboratory Systems A fault detection and diagnosis technique for multivariate processes using a PLS-decomposition of the measurement space, Chemom. Intell. Lab. Syst. 128 (2013) 25–36. doi:10.1016/j.chemolab.2013.07.006.
- [64] C.F. So, J.W.Y. Chung, M.S.M. Siu, T.K.S. Wong, Improved stability of blood glucose measurement in humans using near infrared spectroscopy, Spectroscopy. 25 (2011) 137–145. doi:10.3233/SPE-2011-0507.
- [65] S. Ramasahayam, K.S. Haindavi, B. Kavala, S.R. Chowdhury, Non invasive estimation of blood glucose using near infra red spectroscopy and double regression analysis, Proc. Int. Conf. Sens. Technol. ICST. (2013) 627–631. doi:10.1109/ICSensT.2013.6727729.
- [66] T. Yano, H. Matsushige, K.I. Suehara, Y. Nakano, Measurement of the concentrations of glucose and lactic acid in peritoneal dialysis solutions using near-infrared spectroscopy, J. Biosci. Bioeng. 90 (2000) 540–544. doi:10.1016/S1389-1723(01)80037-2.
- [67] E. Nakamachi, Development of three dimensional blood vessel search system by using on stereo and autofocus hybrid method, Eng. Med. Biol. Soc. EMBC, 2011 Annu. Int. Conf. IEEE. (2011) 6142–6145. doi:10.1109/IEMBS.2011.6091517.
- [68] A.L.Q. Baddini, L.E.R. da Cunha, A.M.C. de Oliveira, R.J. Cassella, Determination of total protein in hyperimmune serum samples by near-infrared spectrometry and multivariate calibration, Anal. Biochem. 397 (2010) 175–180. doi:http://dx.doi.org/10.1016/j.ab.2009.10.012.
- [69] N. Cao, T. Gao, Noninvasive Tissue Blood Oxygenation Measurement Based on Near Infrared Spectroscopy (NIRS), Bioinforma. Biomed. Eng. , 2009. ICBBE 2009. 3rd Int. Conf. (2009) 1–4. doi:10.1109/ICBBE.2009.5163118.
- [70] A. Matas, M.G. Sowa, G. Taylor, H.H. Mantsch, Melanin as a confounding factor in near infrared spectroscopy of skin, Vib. Spectrosc. 28 (2002) 45–52. doi:http://dx.doi.org/10.1016/S0924-2031(01)00144-8.

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