RESEARCH REPORT UMP GRANT
Laporan Prestasi Skim Geran UMP

Final	√	Progress		*Progress Period :*	√ *Please tick*

PROJECT DETAILS *(Keterangan Projek)*

A	**Grant No**	**RDU1703231**
	Faculty/CoE	FKEE
	Project Title	**DEVELOPMENT OF DRIFT CONVERSION ALGORITHM FOR ISFET BASED PH SENSOR FOR CONTINUOUS MEASUREMENT SYSTEM**
	Project Leader	MD RIZAL BIN OTHMAN
	Project Member	1. **MUHAMMAD SHARFI BIN NAJIB** 2. **RAZALI BIN MUDA** 3. **MOHD HERWAN BIN SULAIMAN** 4. **NURUL HAZLINA BINTI NOORDIN** 5. **AMRAN BIN ABDUL HADI** 6. **KAMALUDIN MOHAMAD YUSOF (UTM)** 7. **DR.MOHD ISMAHADI SYONO (MIMOS)**

PROJECT ACHIEVEMENT *(Pencapaian Projek)*

B

ACHIEVEMENT PERCENTAGE				
Project progress according to milestones achieved up to this period	**0 - 25%**	**26 - 50%**	**51 - 75%**	**76 - 100%**
Percentage (please state %)				100%

EXPENDITURE *(Perbelanjaan)*

C

Budget Approved *Peruntukan diluluskan*	**Amount Spent** *Jumlah Perbelanjaan*	**Balance** *Baki*	**% of Amount Spent** *Peratusan Belanja*
RM 23,000.00	**RM 17,743.28**	**RM 5,256.72**	**77.14%**

RESEARCH OUTPUT *(Output Penyelidikan)*

D

NO OF PUBLICATION

KPI FOR NO OF PUBLICATION

	ISI	Scopus	Index Proceedings	Others
KPI		**1**		
Achievement		**1**		

The contribution of funder (UMP, MOHE, MOSTI, Industry etc.) as the fund provider must be acknowledged at all times in all forms of publications. Please state the grant number (RDU/UIC) and grant name.

Number of articles/ manuscripts/books *(Please attach the First Page of Publication)*	**ISI**	**Scopus**
	1. 2.	1. DRIFT COMPENSATION FOR PH ISFET SENSOR USING NARX

		NEURAL NETWORKS 2.
Conference Proceeding *(Please attach the First Page of Publication)*	**International** 1. 2.	**National** 1. 2.

HUMAN CAPITAL DEVELOPMENT

KPI FOR HUMAN CAPITAL DEVELOPMENT

	PhD Student	Master Student
KPI		**1**
Achievement		**1**

Human Capital Development	**Number**				**Others** (please specify)
	On-going		**Graduated**		
Citizen	Malaysian	Non Malaysian	Malaysian	Non Malaysian	
PhD Student					
Masters Student			1		
Undergraduate Student			1		
Total			2		

Name of Student: **ID Matric No:** **Faculty:** **Thesis title:** **Graduation Year:**	**MOHAMMAD IQWHANUS SYAFFA BIN AMIR** MEL16008 FKEE AN ARTIFICIAL NEURAL NETWORK APPROACH FOR CLASSIFICATION AND PREDICTION OF LOW PRESSURE CHEMICAL VAPOR DEPOSITION SiXNY ISFET PH SENSOR DRIFT 2019
Name of Student: **ID Matric No:** **Faculty:** **Thesis title:** **Graduation Year:** *** enter for more space*	**MUHAMMAD MUNZIR BIN HUSSIN** EA14028 FKEE A Study of Output Conversion Method for ISFET-based pH Sensor 2018

INTELECTUAL PROPERTIES

KPI FOR INTELECTUAL PROPERTIES

Patent, Copyright, Trademark,Industrial Design: ____________

Patent, Copyright, Trademark, Industrial Design ect	

OTHERS

KPI FOR OTHERS

Prototype, Technology,Collaborations etc: _____________

	Prototype, Technology, Collaborations etc	

ASSET *(Aset)*

E

Bil	**Peralatan** *(Equipment)*	**Model**	**No Daftar Aset** *(Asset Tagging No)*	**Amount** (RM)	**Lokasi** *(Location)*

PRODUCT DESCRIPTION FOR UMP R&D DIRECTORY (SHORT & BRIEF) *Only for Final Report*

F

PRODUCT PICTURE FOR UMP R&D DIRECTORY *Only for Final Report*

G

SUMMARY OF RESEARCH FINDINGS (*Ringkasan Penemuan Projek Penyelidikan)*

H

In an ion-sensitive field-effect transistor (ISFET) sensor, the ions within the sample media undergo multiple environments influenced reactions occurring molecules from these reactions to accumulate upon the gate oxide layer. The change in charge affects the conductance in the ISFET channels; consequently, the changes of conductance within the source and the drain will produce an electrical signal. The most common problem is drift happens when the electrical signal output gradually changes independent of the measured sample. The primary goal of this study is to investigate a reliable artificial neural network model to classify and predict the error of low-pressure chemical vapour deposition Si_xN_y ISFET pH sensor and implement the drift compensation. Such models could be later used to encounter the drift problems that usually exist in chemical sensors. Three units of ISFET sensors were used to calibrate with three types of pH buffer solutions viz. pH 4, pH 7 and pH 10. Artificial neural networks were applied to construct black-box multiple-input multiple-output models of the ISFET data where the percentage accuracy value was used to assess the model's performances in classifying while the mean squared error (MSE) and the coefficient of determination (R^2) parameter used in determining the best models in predicting the error in the ISFET sensors. Concerning the model structure in classification, Pattern Recognition Neural Network (PATTERNNET) proved to perform better than Function Fitting (FITNET) networks with 100% accuracy. The network configuration in PATTERNNET, a dual-layered network with 30 nodes on the first hidden layer and 3 nodes on the second hidden layer achieved the best results. As for the prediction, the NARX-BR model with 75 delays produce an efficient model in predicting the error of ISFET data set. The value of MSE = $4.8814e^{-5}$ and R^2 = 0.99930 for the NARX-BR model revealed that the model capable in predicting the error. The drift compensation applied and the drift issues in the ISFET sensors has successfully solved. As a result, this study demonstrates great potential in developing artificial neural networks to stave off the drift issues in ISFET low-pressure chemical vapour deposition Si_xN_y ISFET pH sensor.

PROBLEMS / CONSTRAINTS IF ANY *(Masalah/ Kekangan sekiranya ada)*	
I	
Date : *Tarikh* ***01/07/2020***	**Project Leader's Signature:** *Tandatangan Ketua Projek*
COMMENTS, IF ANY/ ENDORSEMENT BY FACULTY *(Komen, sekiranya ada / Pengesahan oleh Fakulti)*	
J	**Recommend / Not Recommend / KIV / Need Ammendment** …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… **Name:** *Nama:* **Signature:** *Tandatangan:* **Date:** *Tarikh:* **** Dean/TDR/Director/Deputy Director**
COMMENTS, IF ANY/ ENDORSEMENT BY RMC PNI *(Komen, sekiranya ada / Pengesahan oleh RMC PNI)*	
K	**Recommend / Not Recommend / KIV / Need Ammendment** …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… **Name:** *Nama:* **Signature:** *Tandatangan:* **Date:** *Tarikh:*

Appendix A

Background of work

Over the past many decades, a significant study has been paid to Ion Selective field effect transistor (ISFET) sensor in the field of medical, environment sensing, agriculture and liquid waste management. ISFET based sensor is considered as a solid state device incorporating the chemical sensitivity exhibited by a membrane and the field sensing capability of a field effect transistor (FET). Bergveld first introduced it in 1970 (Piet Bergveld, 1970), and the principle of operation is based on the theory of electrochemical equilibria between the adjacent phases. Commonly, there are two types of planar field effect transistor based, referring to their fabrication; ISFET and insulated-gate field-effect transistors (IGFET).

The ISFET structure was almost same like IGFET, but the metal gate terminal is changed to an ion-selective membrane, reference electrode and an electrolyte. In ISFET functionality, the value of the current flow will be not only limited by the interacting charges in the dielectric of the gate terminal but also sensitive to various ions, enzyme reactions, pH, etc. The IGFET architecture is particularly MOSFET (metal-oxide-semiconductor field-effect transistor) and the structure of the terminal of the gate electrically separated from the drain and source terminals. An interesting characteristic of FETs is that it is potential to identify biomolecular interactions in a label-free manner within a direct change in electrical conductance characteristic. One advantage of the semiconductor-based biosensors like ISFETs, is their suitability for application in small compact measurement systems and simple to combine into the electronic circuits.

Because of the ISFET device is small and light might be suitable use in a portable monitoring system such as environment monitoring system, health monitoring system and industrial monitoring system. In term of sensor specificity and sensitivity and, both the fabrication of a nano-scale device and rejection of nonspecific molecular adsorption will provide an enhancement in the ISFET sensor detection limit and selectivity. Other advantages ISFET is robustness, low-cost manufacturing and implementing advanced intelligent sensor systems based on the complementary metal-oxide-semiconductor (CMOS) technology.

In most of the system application, ISFET sensor need to be used continuously in liquid based solution and most of the ISFET sensors have an issue to maintain the good analogue output. The instability of threshold voltage, also recognised as drift, has usually existed in ISFET. Drift is defined by a relatively slow, unidirectional temporal variation in the threshold voltage and, therefore, in the ISFET drain current in the inadequacy of changes in the given ion concentration (Jamasb, 2016). Drift is unpredictable and may happen in different situations, for instance, the device size, surface material and pH solution. The excellent accuracy needed for plasma pH vivo continuous monitoring requires precise requirements on the tolerable drift rate in pH-sensitive ISFETs. For instance, blood pH continuous monitoring while surgery demands 0.02 pH unit over 10 hours accuracy without recalibration. An ISFET with ideal sensitivity operating in the feedback mode, such an accuracy amounts to a maximum similar drift rate of 0.002pH per hour or a maximum average drift rate of (61.8mV/pH)(0.002pH/hour)=0.12mV/hour in the measuring signal at the normal body temperature of 36.85 Celsius. In pH-sensitive ISFETs applying complementary metal-oxide-semiconductor compatible inorganic gate insulators, for instance, silicon nitride, the expected long-term drift rate at neutral pH is on the order of several tenths of a millivolt per hour following an exposure time interval within 12 to 16 hours. A drift rate of such magnitude, hence, does not meet the strict stability specifications for in vivo continuous monitoring without a compensation scheme or drift correction.

The artificial neural network is a simplified mathematic design of the biological network structure. The artificial neural network (ANN) history began in 1943 and was presented by Pitts and McCulloch (Jasnickiy, 2005).It is an artificial intelligence to imitate the biological system or natural information by pattern recognition. Neural network is useful for pattern recognition function due to its flexibility, fault tolerance and robustness. The network can change to a new situation automatically without ant pre-programmed configuration or settings and capable of accomplishing tasks including nonlinear statistical model and dealing with the variable pattern of data conditions, for instance, probabilistic, noisy, inconsistent and fuzzy (Yegnanarayana, 2009; Lingireddy and Brion, 2005; Das and Thankachan, 2013).

In the past few years, ANN has rapidly improved in various engineering applications as a learning method to accomplish complicated tasks, as well as language processing, high nonlinear modelling, system control and image analysis. The ANN show interesting features, such as the capability of generalisation, fault tolerance, error compensation, universal approximation, generalisation, classification, clustering and prediction. Furthermore, it is explained that ANN based prediction or approximation of measurement data execute better than the classical methods of data interpolation, in particular, the mean square regression. Therefore, ANN is usually applied for measurement chemical sensor systems, in this research, several works have been described in, where the applications propose to enhance the selectivity, sensitivity, and reliability of ISFET sensor.

Problem statement

Electrochemical sensors such as ISFET pH sensors are popular in agricultural, water quality, swimming pools, environmental monitoring, manufacturing, and medical fields. One of the ISFET sensor advantages is a small sensor size where readings can be done directly on the test sample and suitable for liquid and semi-solid materials measurement. This flexibility makes the use of ISFET sensor cuffs widespread in various commercial industries.

However, some weaknesses need to be addressed especially in the issue of sensor drift over time. The same problem also occurs with the Low-Pressure Chemical Vapor Deposition Si_xN_y ISFET pH sensor developed by MIMOS Berhad. This pH sensor is used to monitor fertilizer readings which are applied in the agricultural industry and for water quality monitoring for shrimp farming in the aquaculture industry.

Based on these applications, the sensor placed in liquid over a long period, and this is the main factor reading the sensor pH drift. Various methods have been implemented to solve drift issues such as to modify the element sensor in the different type of material, size and packaging. The readout board modification is also quite popular, especially in threshold detection alteration and the circuit improvement for current and voltage conversion. However, such a method must be done individually to each sensor and not a universal solution for every sensor.

Nowadays, the implementation of artificial neural networks is extensive in automation applications, instrumentation control and image analysis. However, the use of artificial neural networks to overcome the problem of sensor drift is less. Based on the study there is not much research applied an artificial neural network to solve the drift problem of Low-Pressure Chemical Vapor Deposition SI_xN_y ISFET pH sensor and the focus of this research is to resolve and compensate the sensor drift issue by using an artificial neural network approach.

Objective

The purpose of this work is to investigate a reliable model of the Neural network for classification and prediction of Low-Pressure Chemical Vapor Deposition Si_xN_y ISFET pH sensor and solved the drift compensation.

1. To setup experiment for continuous data pH collection using ISFET probe
2. To classify drift of Low-Pressure Chemical Vapor Deposition Si_xN_y ISFET pH sensor
3. To predict drift of Low-Pressure Chemical Vapor Deposition Si_xN_y ISFET pH sensor

Data collection

The experiment was conducted by using wireless ISFET pH sensor (figure 3.1) to measure pH 4, pH 7 and pH 10 buffer solutions (figure 3.2). All sensors were set up in the shield box with no interference of lights and any radio frequency as shown in Figure 3.4. This is important to avoid any disturbance that might affect the reading of the sensors. The temperature of the setup room was at 25±1 Celsius, and the wireless sensors were set in an auto-read mode for every 30 minutes and were automatically sent the signal to the receiver. Figure 3.3 shows the correct method to dip the sensor horizontal into the glass beaker filled with a pH buffer solution. The sensor tip has to fully immerse inside the ph buffer solution to get an accurate reading. All data collections for each sensor and pH were collected in a month. The sensor's data were saved in the PC-Based National Instrument Data acquisition for each pH buffer solution. The detail configuration in experiment setup is illustrate in figure 3.5.

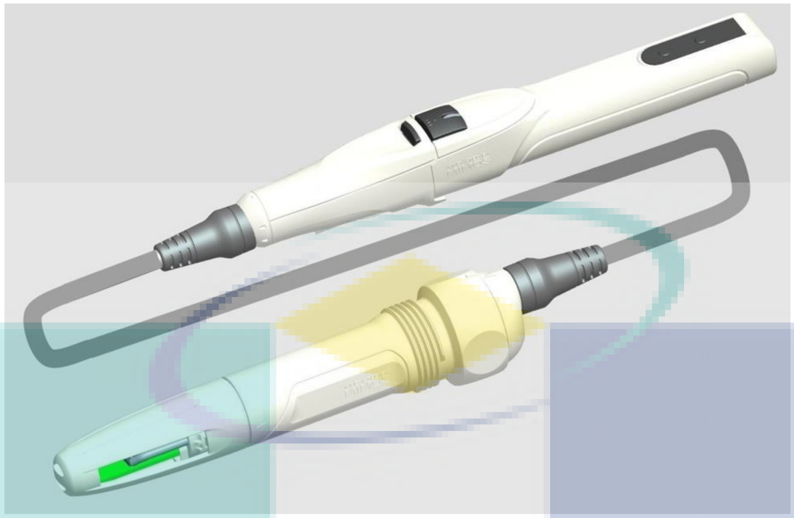

Figure 3.1 Wireless ISFET pH sensor

Figure 3.2 pH Buffer solution (pH 7, pH4 and pH 10)

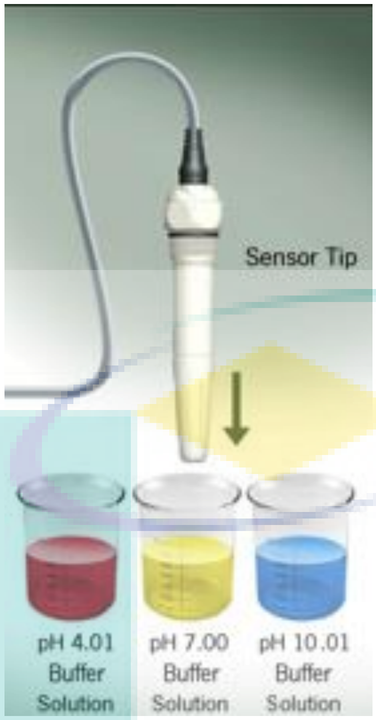

Figure 3.3 Method to dip Sensor into pH buffer

Figure 3.4 Experiment setup in MIMOS Laboratory

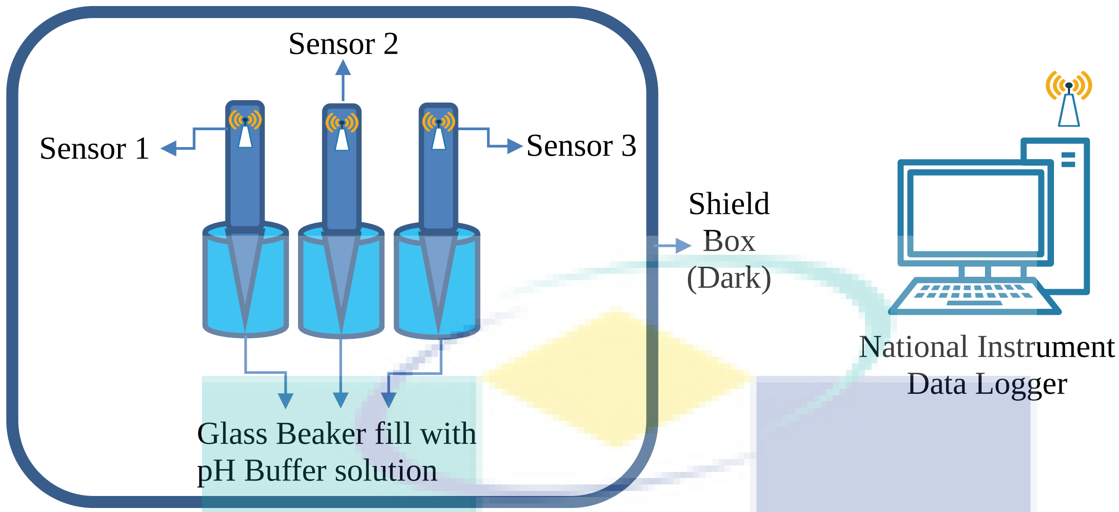

Figure 3.5 Detail configuration in experiment setup

An overview of the data retrieval process for three types of ISFET pH sensors is shown in Figure 3.6. Initially, 3 units of ISFET pH sensors will be provided, and then the preparation of 3 types of buffer solution, ie pH 4, pH 7 and pH 10. This buffer solution will be placed in the test tube for each sensor. After all the setup is completed, PC-Based National Instrument Data Acquisition needs to be set up for data logging activity. Sensor data is transmitted wirelessly to the NI machine and will be stored on the fly every 30 minutes. Data collection will take a month for each pH, and verification will also be made using commercial pH meter. This step is important to ensure the pH buffer solution is at the correct pH. All data will be stored in comma-separated values (CSV) file format.

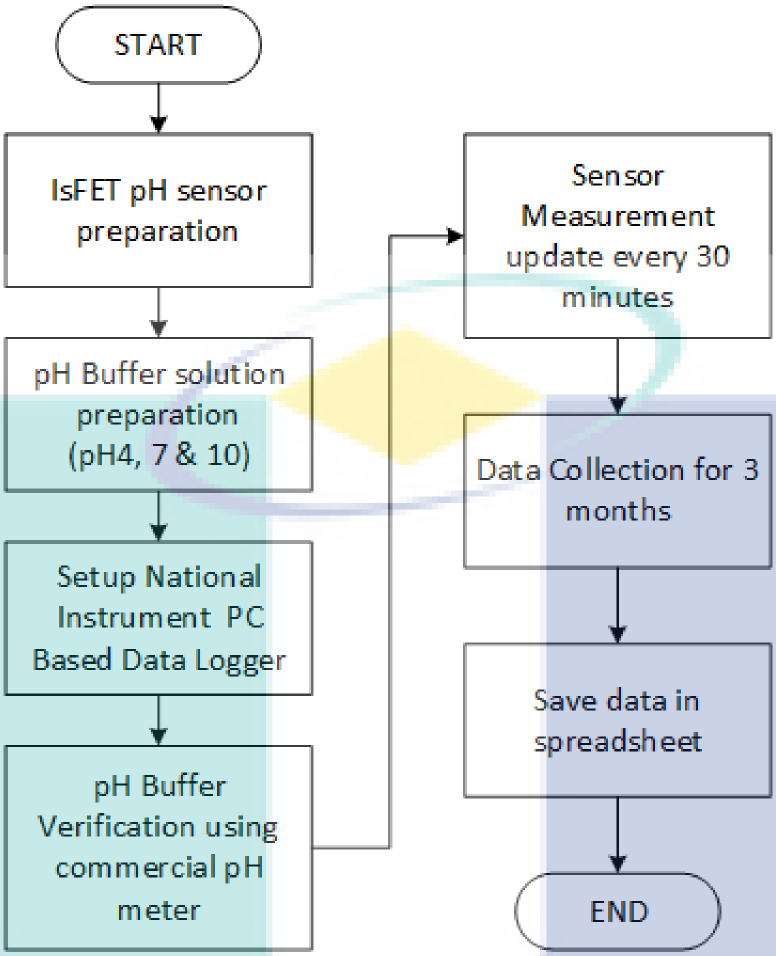

Figure 3.6 pH data collection flow chart

Feature extraction

In the area of machine learning and pattern recognition, dimensionality reduction is essential in improving achievement such as estimated accuracy, learned knowledge comprehensively and visualisation. The output signal of raw data for ISFET 1, ISFET 2 and ISFET 3 in the presence of 3 types of pH 4, pH 7 and pH 10 overlapped each other and this will create difficulties in the next process that is to implement a neural network training.

To overcome this, the Multiscale Principle Component Analysis (MSPCA) had been applied to the data where the data will be separated into multiple time scales using the wavelet transform application (Mirin & Wahab, 2014). Although this study opted MSPCA that build in MATLAB, the theory of MSPCA starts with considering matrix Y representing the ISFET data with the size of $n \times m$ matrix where n is a sample and m is a variable of Y data. Then each of the m variables is decomposed individually by applying wavelet decomposition. Each approximation wavelet is collected in a matrix (Bakshi, 1998) and the original data matrix, Y will be reconstructed in a matrix WY, where W is $n \times n$ orthonormal matrix describing the orthonormal wavelet transformation operator as described below.

$$W = \begin{bmatrix} h_{L,1} & h_{L,2} & \cdots & \cdots & \cdots & \cdots & h_{L,\mathrm{N}} \\ g_{L,1} & g_{L,2} & \vdots & \vdots & \vdots & \vdots & g_{L,N} \\ g_{L-1,1} & \vdots & \vdots & g_{L-1,N/2} & 0 & \vdots & 0 \\ 0 & \vdots & \vdots & 0 & g_{L-1,N/2+1} & \vdots & g_{L-1,N} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ g_{1,1} & g_{1,2} & 0 & \vdots & \vdots & \vdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & \cdots & 0 & g_{,N-1} & g_{1,N} \end{bmatrix} = \begin{bmatrix} H_L \\ G_L \\ G_{L-1} \\ \vdots \\ \vdots \\ G_m \\ \vdots \\ \vdots \\ G_1 \end{bmatrix}$$

where G_m is the $2^{\log_2 n-m} \times n$ is a wavelet filter matrix with $m = 1, 2, 3, \ldots, L$ and H_L is the scaling function filter matrix at the coarsest scale (Bakshi, 1998). In this study, the size matrix that yields from the analysis is 345 x 27.

Figure 3.7 shows the process that runs in MSPCA with data 345 x 27 matrix that involved in this study. The wavelet parameter has to be determined according to the required output, and the value of the retained principal component should also be determined to get the best output. Upon completion of all the appropriate variable settings, then the MSCPA process will be run to obtain the expected data.

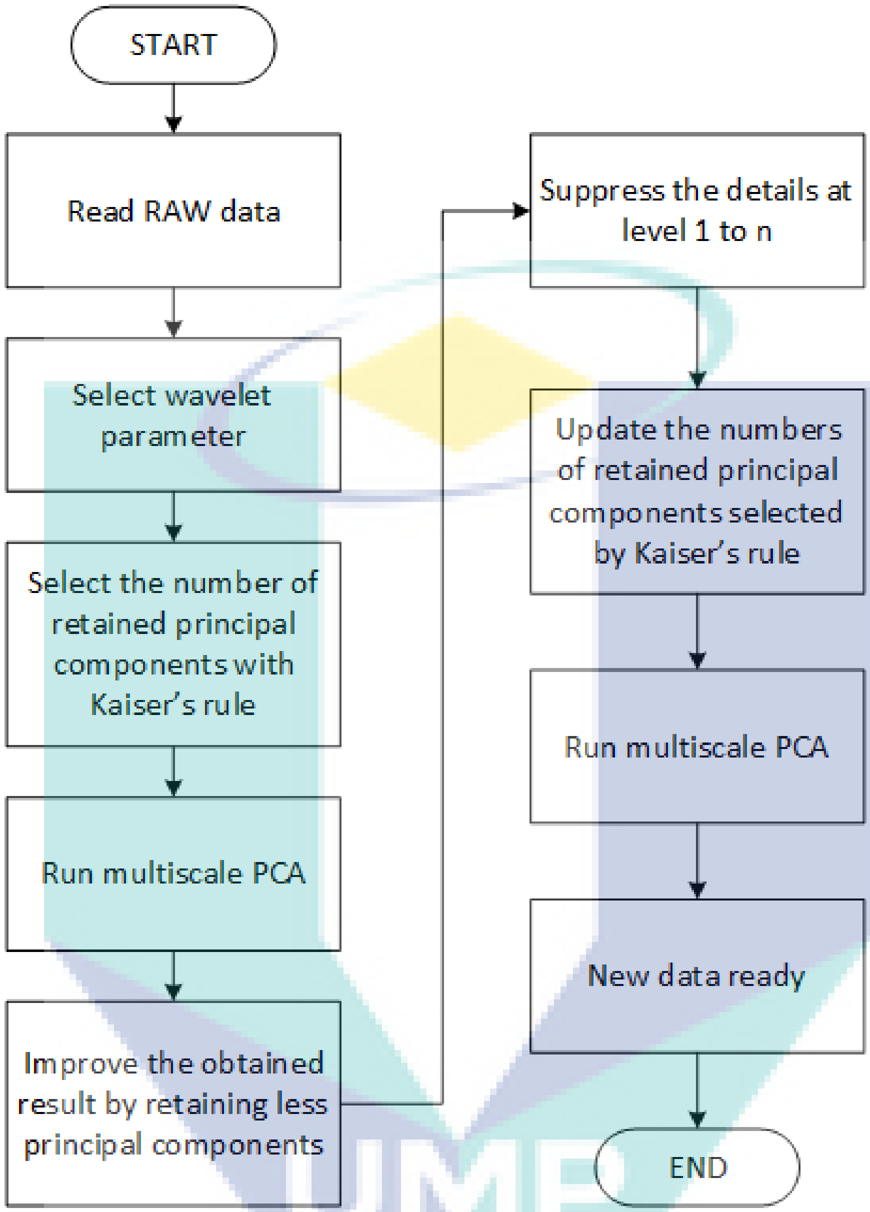

Figure 3.7 Flow chart of MSPCA feature extraction

Conclusion of works

This research has presented the neural network approach to classify and predict of ISFET pH sensor drift. There are 3 objectives to achieve this research.

The first objective of this research is to setup a test environment for ISFET pH sensor by using the type Low-Pressure Chemical Vapor Deposition Si_XN_Y in drift effect issues. The sensor was integrated with wireless Zigbee transceiver to send data to the PC-Based National Instrument Data acquisition. The sensor has placed in the test jig with light and noise isolation. The data acquisition has been collected every 30 minutes for 1 month which applied to each sensor with pH 4, pH 7 and pH 10 buffer solution.

The second objective of this work is to evaluate which neural network is capable of performing classification for ISFET pH sensor drift. The objective achieved through the comparison between PATTERNNET and FITNET neural network with different hidden layer and training algorithms. The PATTERNNET neural network more accurate compared to FITNET. The FITNET methods will produce 98.8 % accuracy with four neurons in hidden layer while the most suitable classification neural network is PATTERNNET method produces 100 % accuracy by using trainscg training algorithm with thirty neurons in hidden layer.

The third objective of this work is to evaluate which neural network can perform better prediction for ISFET pH sensor drift. The comparison with NARX, NAR and TDNN have simulated with various delay and different training algorithm. TDNN methods produce R^2 = 0.95511 with 75 delays. However, NAR method produces a much better value which is R^2 = 0.99929 with the same delay. The most suitable neural network for prediction is NARX with R^2 = 0.99930 by using BR training algorithm with 75 delays.