Data Acquisition for ISFET pH Sensor System by Using Seeeduino Stalker as a Controller

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***Abstract* – This paper is about data acquisition for ISFET pH sensor system by using Seeeduino Stalker as a controller. ISFET pH sensor formed with reference electrode, which the function of reference electrode is to replace the gate of ISFET, is used in this project. Readout interface circuit is also used to produce the voltage response that is obtained from the ISFET sensor. The data are collected from pH4, pH7 and pH10. ISFET pH sensor and reference electrode are placed inside the pH solution and connected with the readout circuit. The voltage response that is obtained from the output of the readout circuit is then saved in the memory card on the Seeeduino Stalker. Data collected from April to May 2013, showed that voltage response for pH 4 is higher than pH7 and pH10. The objective of this project is to develop a measurement setup to collect the data from ISFET experiment especially the voltage response for every pH and the data from the readout circuit. Overall, this project objective achieved after the pH sample was tested from April to May 2013. The setup is successfully developed as the voltage response for every pH solution is complete collected from April to May 2013 and is saved in the data logger by using Seeeduino Stalker as a controller.**

I. INTRODUCTION

Chemical sensors are the sensors that can convert chemical information to electrical response. One of the chemical sensors that widely use nowadays is the ion-sensitive field effect transistor (ISFET). ISFETs are electrochemical sensors that create electrical response same as metal-oxide field effect transistor application [1]. To modify the ISFET from MOSFET, the polysilicon that forms the metal gate of a MOSFET is removed for the structure to be hydrogen ion-sensitive [2]. Then, in order for the ISFET to extend the sensitivity to any different type of ions, ion selective membranes are placed above the gate dielectric [3].The modifications from MOSFET to ISFET are illustrated for comparison in Fig. 1 [4].

Since Bergveld [2] released that ISFET can measure ion concentrations in solutions, there are many kinds of chemical sensors that have been produced. For almost 30 years, ISFET was rapidly developed [5]. ISFET advantages such as high sensitivity, very fast response time, micro-size, consistancy and the ability for on-chip circuit integration caused this sensor to be commonly used in biomedical areas such as monitoring clinical or environmental samples, medical diagnostics, fermentation and bioprocess control and testing pharmaceutical or food products [6]. There are several examples of ISFET application in medical area such as ISFET-based penicillin sensor [7], ISFET-based zeta potential analyzer for protein detection [8] and ISFET glucose sensor[9] and urea detection [10]. Gonçalves [11] created amorphous silicon-based ISFET to detect DNA and protein biological molecules. Risveden [12] developed bioelectronic region ISFETs to detect glucose and Park [13] build an ISFET biosensor for the monitoring of maltose-induced change in myelin basic protein (MBP). Rozina and Othman S. [14] have been developed the ISFET pH sensor towards biosensor microchip application.

The voltage response for this ISFET pH sensor is important to understand the characteristics such as the sensor's sensitivity. This work presents the technique used to collect data for pH4, pH7 and pH10 which is the voltage response for each pH. The reference electrode is placed in the electrolyte in order to replace the gate while the insulator named Ion Sensitive Membrane (ISM) interacts directly to the solution and when the exposed surfaces change with the pH value of the solution, it will change the threshold voltage of the ISFET. The voltage response will be obtained from the readout interface circuit and collected by using Seeeduino Stalker. The data for every pH is then saved in the memory card and displayed by using Microsoft Excel and Visual Basic as an option.

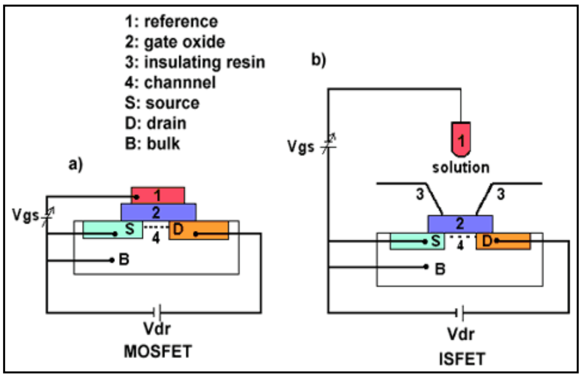


Figure 1. Cross section of MOSFET and ISFET

II. TEST SETUP DEVELOPMENT

Fig. 2 shows the setup of the data acquisition block diagram. There are 3 types of pH level used in this work which are pH4, pH7 and pH10. Data collection is done using ISFET pH sensor that is connected with readout interface circuit. The output from the readout interface circuit will then be saved in the memory card of Seeeduino Stalker data logger. The ISFET pH sensor is dipped inside the pH solution with the reference electrode together. The 3V power supply is connected with readout interface circuit and the output from readout interface circuit is connected to the input of the data logger. Those data that have been saved in the memory card are save in ".csv" format are inserted to excel. The data can also be sent to Microsoft Visual Basic 2010 software to display the table and also graph of the data.

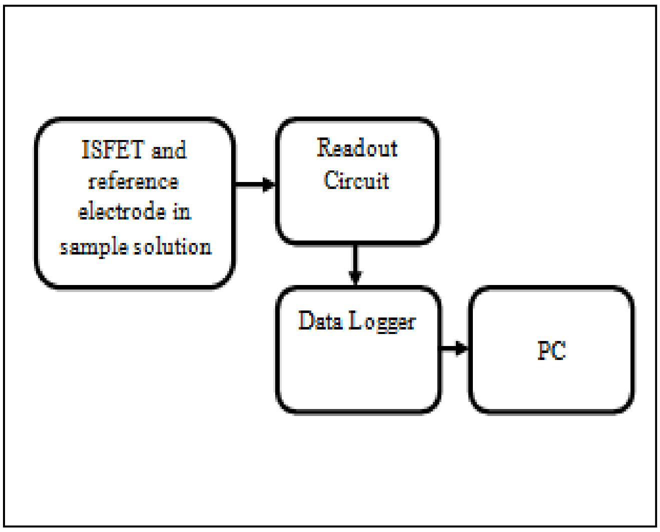


Figure 2. Data Acquisition block diagram

Flowchart in Fig. 3 explains the overall process of this project. Firstly, ISFET pH sensor is dipped inside the pH solution together with the reference electrode. Bulk, source and drain and also the reference electrode will be connected to the input of the readout circuit. The output of the readout circuit is ten connected to the input of the Seeeduino Stalker at the PC. When the circuit is ON, ISFET will send the change of the threshold voltage to the readout circuit. Then, the readout circuit send the voltage response to the Seeeduino Stalker. Before it saves the data in the memory card, Seeeduino Stalker will take 60 data in one minute according to the program that has been set. The data that saved in the memory card will then be opened using excel and also Visual Basic to display the table and the graph of the voltage response of the pH solution. This process will be repeated for other pH solution.

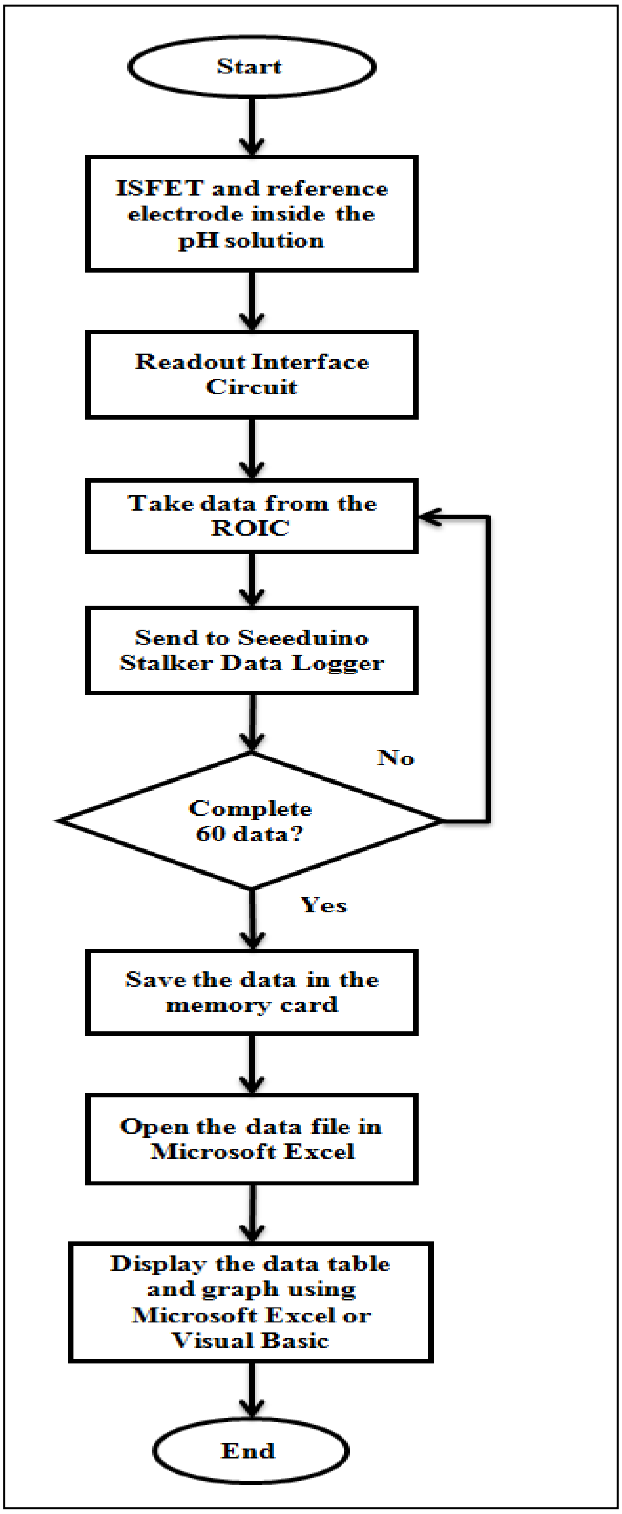


Figure 3. Flowchart of the overall project

A. *ISFET pH sensor*

Firstly, ISFET sensor is used to complete this project. The ISFET pH sensors operated when the conversion of pH changes into a corresponding threshold voltage. Commonly used pH sensitive gate materials include silicon dioxide (SiO_2)

and tantalum pentaoxide (Ta_2O_5). Reference electrode is also used to replace the ISFET gate. The complete setup of ISFET pH sensor and reference electrode placed inside the solution can be seen in Fig. 4.

Ion-selective field effect transistors (ISFET) which are sensitive to hydronium ion concentration can be used to measure pH changes in solution. ISFET pH sensing relies on a transistor with an electroactive gate that restricts electric current flow as a function of hydronium ion concentration. Changes in ion concentration alter the current flowing through the transistor. The difference between ISFET and MOSFET is the ISFET structure where the metal gate of the MOSFET is replaced by the combination of reference electrode, electrolyte and insulator or membrane [15]. This sensors work when the gate insulator senses the H^+ ions in the pH solution then generating an interface potential at the gate of ISFET and change the drain-source current in the semiconductor channel. The channel will be affected by the potential at gate which would alter the current flow that crosses at the source and drain when the sensor is turned ON. The insulator or membrane sensitivity depends on the number of H^+ ions of the solutions. Every pH has different hydrogen, H^+ and hydroxyl, OH^- ions. The sensor responses are then measured from the readout interface circuits and saved in the data logger.

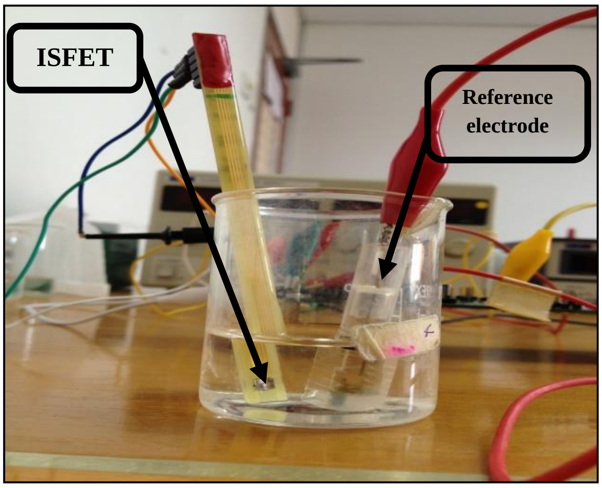


Figure 4. ISFET and reference electrode

B. Readout Interface Circuit

The purpose of using the readout interface circuit is to produce a voltage response to ionic concentration change based on the threshold voltage modification effect in the solution at the gate or membrane of sensor. The output of the readout circuit is the data that will be saved in the data logger memory card that also communicates with the PC to open the data using Excel or Visual Basic. Fig. 5 shows the readout interface circuit that is used in this project.

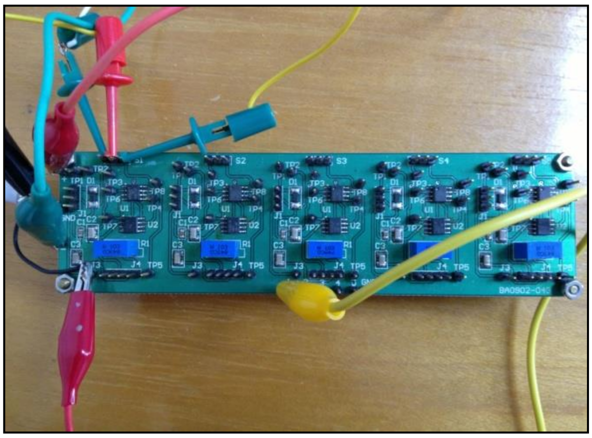


Figure 5. Readout interface circuit

C. Seeeduino Stalker Data Logger

Seeeduino Stalker is a feature of Arduino that compatible with Wireless Sensor Network node with data logger functionality. It is a modular structure and onboard peripherals make it convenient to log time stamped sensor data on a periodic basis. Seeeduino Stalker comes with a Temperature sensor, Real-Time Clock (RTC) with backup power, SD Card Socket, Bee Socket and Solar Lithium Polymer (LiPo) Battery Charger. The Seeeduino Stalker is a good candidate for all tracking, monitoring and control projects. Seeeduino stalker used in this project is version 2.3 and it can be programmed with Arduino Processing language. This Seeeduino Stalker also has ATMega328P microcontroller. Fig. 6 shows the Seeeduino Stalker v2.3.

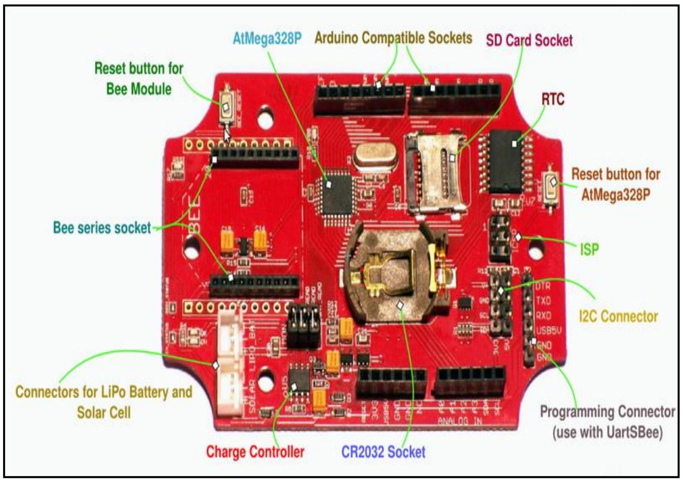


Figure 6. Seeeduino Stalker v2.3

To begin the data logging in the Seeeduino, time is synchronised with a real time clock. Then, it will be programmed to log the data automatically according to the specific time set in the programming. At every second for one minute duration, it will collect one data. Once the data is completely collected, it will be saved in the memory card. This system will collect data for every pH in one day but at different time. Using the data, the sensitivity of sensor can be calculated from the graph as Equation (1) and (2);

$$y = mx + c \tag{1}$$

$$\text{Sensitivity,m} = (y-c)/x \tag{2}$$

IV. RESULTS AND DISCUSSION

In this work, the data is collected for several days from April until May 2013. The reason data was taken for several days were because the voltage responses are not constant for each day due to the ISFET sensor itself that is very sensitive with the temperature. Furthermore, the concentrations of the pH solution change too. Table 1 will only shows the voltage response taken in the early and at the end of April and May 2013 to see clearly whether it is have a different when the data is taking for the first time and after the data is take for a month.

TABLE I: EXAMPLES OF DATA TAKEN FOR SELECTED DAYS

Date \ pH	4	7	10
1/4/2013	0.0781V	0.0293V	0.0025V
30/4/2013	0.0878V	0.0146V	0.0046V
1/5/2013	0.0732V	0.0146V	0.0016V
31/5/2013	0.0781V	0.0146V	0.0097V

Reading shows that the voltage response for ph4 is higher than pH7 and pH10. This is due to the fact that acidic solution has more hydrogen than neutral and alkaline solution. Fig. 7 shows the graph from the Table 1. It is observed that it gives negative slope for each date in April and May 2013. The value of voltage response for pH7 is slightly different in the early April 2013 than the other values, this is because the pH solution has been used many time after the first take. The graph slope is also different for the each date in April and May 2013. This is due to the fact that any changes in temperature will also affect the solutions and the ISFET pH sensor characteristic which is very sensitive to the temperature [16] .

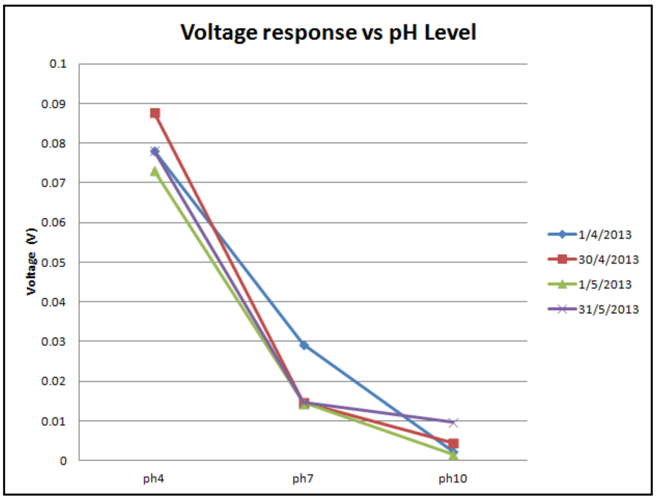


Figure 7. Graph for the Table I

From the graph above, the sensitivity is then calculated as (2):

For 1/4/2013:

Sensitivity,m = (0.0293– 0.0781)/3 = -0.0162V/dec

For 30/4/2013:

Sensitivity,m = (0.0146 – 0.0878)/3 = -0.0244V/dec

For 1/5/2013:

Sensitivity,m = (0.0146 – 0.0732)/3 = -0.0195V/dec

For 31/5/2013:

Sensitivity,m = (0.0146 – 0.0781)/3 = -0.0212V/dec

From the calculation above, the average sensitivity for the ISFET sensor used in this project is about -0.02V from April until May 2013.

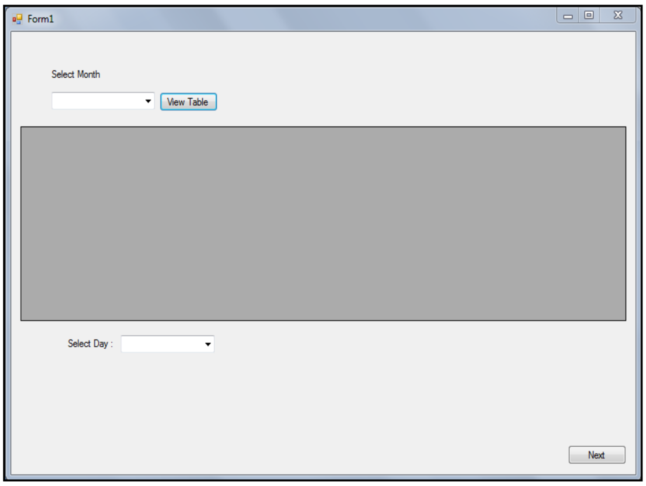
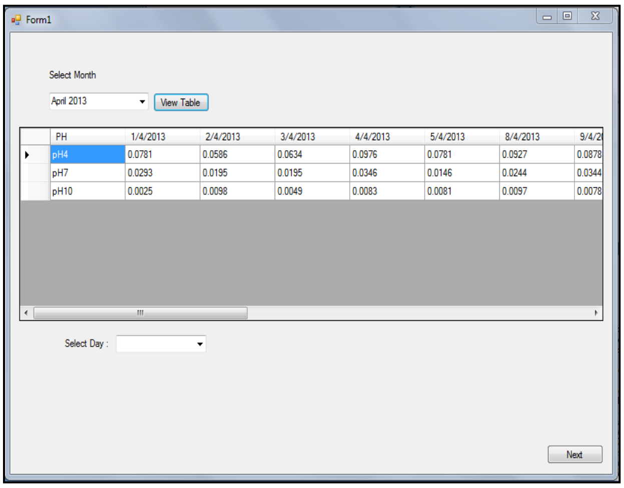


Figure 8. Visual Basic display form

The data is then displayed in Visual Basic. Fig. 8 shows the form to display the table for April or May 2013. Fig. 9 shows the tabulated data while the plotted graph is shown in Fig. 10. The ‘Back’ button used to go back to the table and select other date and the ‘Finish’ button is to exit the system.



PH	1/4/2013	2/4/2013	3/4/2013	4/4/2013	5/4/2013	8/4/2013	9/4/2
pH4	0.0781	0.0586	0.0634	0.0976	0.0781	0.0927	0.0878
pH7	0.0293	0.0195	0.0195	0.0346	0.0146	0.0244	0.0344
pH10	0.0025	0.0098	0.0049	0.0083	0.0081	0.0097	0.0078

Figure 9. Visual Basic display table

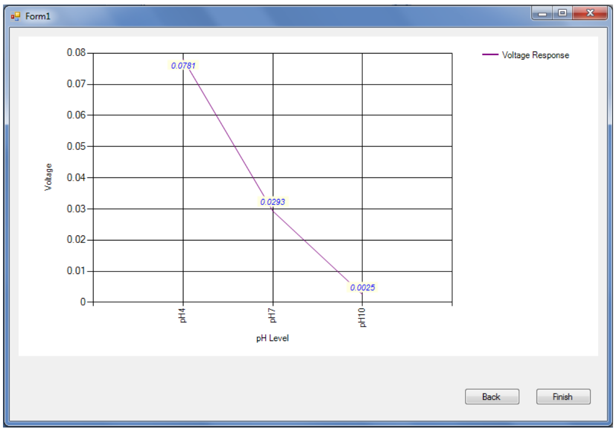


Figure 10. Visual Basic display graph

V. CONCLUSION

As a conclusion, the setup for pH data collection is successfully built. The voltage responses for each pH are collected using ISFET pH sensor and a reference electrode. From the table and graph for April and May 2013, the sensitivity is calculated and the value of sensitivity for those months is similar. From April to May 2013, the voltage response is higher for pH4 than voltage response for pH7 and pH10.The shape of those graphs are also almost similar and showed that the voltage responses that are collected for two months do not have much different and shows that ISFET sensor is working. Therefore, the objective of data acquisition for ISFET pH sensor system by using Seeeduino Stalker as a controller is achieved.

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REFERENCES

[1] M. O. Wan Fazlida Hanim Abdullah, Mohd Alaudin Mohd Ali, "Ion-Selective Field-Effect Transistor Sensor Response for Neural Network Supervised Learning," ed. Kuala Lumpur, Malaysia, 2008.

[2] P. Bergveld, "Development of an ion-sensitive solid-state device for neurophysiological measurements," pp. 70-71, 1970.

[3] J. Janata, & Huber, F. J., "Chemically Sensitive Field-Effect Transistors. In Ion Selective Electrodes in Analytical ChemistryIon Selective Electrodes in Analytical Chemistry," pp. 107-174, 1980.

[4] W. Wroblewski. (10.11.2012). *Field effect transistors (FETs) as transducers in electrochemical sensors*. Available: http://csrg.ch.pw.edu.pl/tutorials/isfet/

[5] P. Bergveld, "Thirty years of ISFETOLOGY: What happened in the past 30 years and what may happen in the next 30 years," *Sensors and Actuators B: Chemical*, pp. 1-20, 2003.

[6] S. B. C. K. Y. Park, M. Lee, B. K. Sohn, and and S. Y. Choi, "ISFET glucose sensor system with fast recovery characteristics by employing electrolysis," *Sensors and Actuators B:*, vol. 4169, 2002.

[7] M. J. S. A. Phogossian, P. Schroth, A. and a. H. L. Simonis, "An ISFET-based penicillin sensor with high sensitivity, low detection limit and long lifetime," *Sensors and Actuators B*, vol. 76, pp. 519-526, 2001.

[8] P. W. S. Koch, L. K. Meixner, S. Drost, and and H. Wolf, "Protein detection with a novel ISFET-based zeta potential analyzer," *Biosensors & Bioelectronics*, vol. 14, pp. 413-421, 1999.

[9] M. L. K. Y. Park, and B. K. Sohn, "Improved recovery characteristics of ISFET glucose sensor using electrolysis method," *Electronics Lett.*, vol. 37(8), 2001.

[10] M. L. P. W. Sant, J. Launay, T. Do Conto, and a. P. T.-B. A. Martinez, "Development of chemical field effect transistors for the detection of urea," *Sensors and Actuators B*, vol. 95, pp. 309-314, 2003.

[11] D. Gonçalves, Prazeres, D. M. F., Chu, V., & Conde, J. P., "Detection of DNA and proteins using amorphous silicon ion-sensitive thin-film field effect transistors," *Biosensors and Bioelectronics*, vol. 24(4), pp. 545-551, 2008.

[12] K. Risveden, Pontén, J. F., Calander, N., Willander, M., & Danielsson, B., "Theregion ion sensitive field effect transistor, a novel bioelectronic nanosensor.," *Biosensors and Bioelectronics*, vol. 22(12), 2007.

[13] H.-J. Park, Kim, S. K., Park, K., Lyu, H.-K., Lee, C.-S., Chung, S. J., Yun, W. S., and M. Kim, & Chung, B. H., "An ISFET biosensor for the monitoring ofmaltose-induced conformational changes in MBP," *FEBS Letters*, vol. 583(1), pp. 157-162, 2009.

[14] R. A. R. a. O. Sidek, "ISFET pH Sensor characterization: towards Biosensor MicrochipApplication," Universiti Sains Malaysia.

[15] S. M. K. S. Swaminathan, W. K. Lim, Z. and a. G. C. Ahmed, "Microsensor Characterization in an integrated blood gas measurement system" 2002.

[16] J. C. C. H. K. Liao, W. Y. Chung, T. P. Sun, and a. S. K. Hsiung, "Study of amorphous tin oxide thin films for ISFET applications," *Sensors and Actuators B*, vol. 50, pp. 104-109, 1998.

[1] M. O. Wan Fazlida Hanim Abdullah, Mohd Alaudin Mohd Ali, "Ion-Selective Field-Effect Transistor Sensor Response for Neural Network Supervised Learning," ed. Kuala Lumpur, Malaysia, 2008.

[2] P. Bergveld, "Development of an ion-sensitive solid-state device for neurophysiological measurements," pp. 70-71, 1970.

[3] J. Janata, & Huber, F. J., "Chemically Sensitive Field-Effect Transistors. In Ion Selective Electrodes in Analytical ChemistryIon Selective Electrodes in Analytical Chemistry," pp. 107-174, 1980.

[4] W. Wroblewski. (10.11.2012). *Field effect transistors (FETs) as transducers in electrochemical sensors*. Available: http://csrg.ch.pw.edu.pl/tutorials/isfet/

[5] P. Bergveld, "Thirty years of ISFETOLOGY: What happened in the past 30 years and what may happen in the next 30 years," *Sensors and Actuators B: Chemical,* pp. 1-20, 2003.

[6] S. B. C. K. Y. Park, M. Lee, B. K. Sohn, and and S. Y. Choi, "ISFET glucose sensor system with fast recovery characteristics by employing electrolysis," *Sensors and Actuators B:,* vol. 4169, 2002.

[7] M. J. S. A. Phogossian, P. Schroth, A. and a. H. L. Simonis, "An ISFET-based penicillin sensor with high sensitivity, low detection limit and long lifetime," *Sensors and Actuators B,* vol. 76, pp. 519-526, 2001.

[8] P. W. S. Koch, L. K. Meixner, S. Drost, and and H. Wolf, "Protein detection with a novel ISFET-based zeta potential analyzer," *Biosensors & Bioelectronics,* vol. 14, pp. 413-421, 1999.

[9] M. L. K. Y. Park, and B. K. Sohn, "Improved recovery characteristics of ISFET glucose sensor using electrolysis method," *Electronics Lett.,* vol. 37(8), 2001.

[10] M. L. P. W. Sant, J. Launay, T. Do Conto, and a. P. T.-B. A. Martinez, "Development of chemical field effect transistors for the detection of urea," *Sensors and Actuators B,* vol. 95, pp. 309-314, 2003.

[11] D. Gonçalves, Prazeres, D. M. F., Chu, V., & Conde, J. P., "Detection of DNA and proteins using amorphous silicon ion-sensitive thin-film field effect transistors," *Biosensors and Bioelectronics,* vol. 24(4), pp. 545-551, 2008.

[12] K. Risveden, Pontén, J. F., Calander, N., Willander, M., & Danielsson, B., "Theregion ion sensitive field effect transistor, a novel bioelectronic nanosensor.," *Biosensors and Bioelectronics,* vol. 22(12), 2007.

[13] H.-J. Park, Kim, S. K., Park, K., Lyu, H.-K., Lee, C.-S., Chung, S. J., Yun, W. S., and M. Kim, & Chung, B. H., "An ISFET biosensor for the monitoring ofmaltose-induced conformational changes in MBP," *FEBS Letters,* vol. 583(1), pp. 157-162, 2009.

[14] R. A. R. a. O. Sidek, "ISFET pH Sensor characterization: towards Biosensor MicrochipApplication," Universiti Sains Malaysia.

[15] S. M. K. S. Swaminathan, W. K. Lim, Z. and a. G. C. Ahmed, "Microsensor Characterization in an integrated blood gas measurement system" 2002.

[16] J. C. C. H. K. Liao, W. Y. Chung, T. P. Sun, and a. S. K. Hsiung, "Study of amorphous tin oxide thin films for ISFET applications," *Sensors and Actuators B,* vol. 50, pp. 104-109, 1998.