IOP Conf. Series: Materials Science and Engineering **370** (2018) 012042 doi:10.1088/1757-899X/370/1/012042

Prediction of Trace Element based Energizing Sensor Control System using PWM

Mohammad Nizar Bin Mohamed Zukri[1], Elmi Bin Abu Bakar[1,*], Naoki Uchiyama[2], Mohamad Nazir Bin Abdullah[3]

[1]School of Aerospace Engineering, Universiti Sains Malaysia, Penang, MALAYSIA.
[2]Department of Mechanical Engineering, Toyohashi University of Technology, Aichi, JAPAN.
School of Electrical and Electronic Engineering, Universiti Sains Malaysia, Penang, MALAYSIA.

*E-mail: meelmi@usm.my

Abstract. A real-time system for field-work monitoring wastewater laden with heavy metal in industrial discharge through wireless communication network was developed. The monitoring system poses an interesting challenge in order to determine existing metal ion in the solution whereas the previous result only consider total dissolve ion. This paper aims to distinguish the metal ion based on reaction determination in solution. The control algorithm was implemented as generating voltage input for energize conductivity sensor since the voltage corresponding to oxidation and reaction based on standard reduction potential. Implementation of ATmega2560 microcontroller for control voltage fed on sensor equivalent to controlling the PWM duty cycle. PID controller was designed uses a microcontroller (Arduino) platform with manual tuning for identify reaction process and sufficient voltage input. From the experimental result, is found that the proposed PI controller has excellent tracking and measurement performance. Low-pass filter was applied in programming to make the system understand that signal has achieved stable. The development of hardware and software of the closed loop system has an enhancement of measurement performance and high feasibility for SME's company in economic point of view. The desired objective is to achieve a system with the stable measurement and sufficient voltage supply. This system will provide an accurate and precise control efficiently without using costly component and complicated circuit.

1. Introduction

Industrial wastewater discharge is a one of major that contribute to water pollution. Water pollution can be characterized as pH level, total suspended solid (TSS), total dissolve solid (TDS), amount of heavy metals, chemical oxygen demand (COD) and biological oxygen demand (BOD) [1]. Recently, many researchers in Malaysia conducted research consider heavy metal existing in order to pertain the environment for sustainable [2].

In a few decades, there are many methods established for determine existing of heavy metal ion in industrial wastewater since the pollutant has an endanger effect to aquatic life and harm human [3]. In general practice, sample from effluent discharge was collected manually and transported to the central

IOP Conf. Series: Materials Science and Engineering **370** (2018) 012042 doi:10.1088/1757-899X/370/1/012042

laboratory to analyses heavy metal contents. Unfortunately, there will give an irrelevant result for heavy metal contents during samples transportation due to light exposure, dissolved oxygen and precipitation, thus the sampling will give inefficient data [4]. Due to environmental threat from wastewater associate with particular risk heavy metal even at low concentration, the development of analytical method with low cost and fast detection method is become interest for most researcher [5].

A variety of inorganic techniques approaches are described in literature for trace elements of heavy metal. The method is difference based on principle and type of analysis. This paper demonstrated simple instrument to determine metal concentration based on electroanalytical method. Electroanalytical is the technique that concern on analytic solution by measure the potential (volt) and current (ampere) in interfacial process of chemical or physics species [6]. From this fundamental concept, this technique can be divided to the various others method based on aspects of the cell controlled and measured. This method is suitable for develop the field work, real-time and on-line environmental analysis due to high performances such as low detection limits, good stability and wide linear response range.

2. Related Works

For nowadays, it will be significantly to SME's industrial consider to measure heavy metal contents to remove and control the toxicants before to release directly into environment through final discharge point. Thus, simplified technique with fast detection device must be develop to monitor the discharge regularly and build a pollution prevention system. The aim of this work is to install the device into final discharge point whereas the data can be quickly and accurately assess the toxic contaminant in the real-field work.

2.1. Block Diagram of System

Figure 1 illustrates the schematic of a PID controller with a feedback loop. The sensor reading block measures the conductivity value for the solution through the conductivity sensor. At initial state, the sensor will read an analogue value from the physical phenomenon, then the analogue value will converted into ion concentration values (ppm). The process variable for the system will represent an absolute value (reading after – reading before) by using low pass filter. Low pass filter is implement in the system to obtain a stable reading. From the stable reading, we can identify and predict the reaction process for electron flow and concentration from a particular solution. Thus, in order to make the system realize the stable reading is achieved, the set point is set for zero. The process variable is aim to approaches the zero reading through the voltage supplied. PID controller uses a feedback loop to control the voltage supply and energize the sensor. The aim of this controller is ensure the process variable close to zero reading by energize the sensor with various voltage. The controller uses an error (the difference between Absolute value and Set Point) in each loop to control the PWM. It will give automatically determine value of various voltage in the system whereas measures the error in each loop and gives the necessary voltage signal to the system.

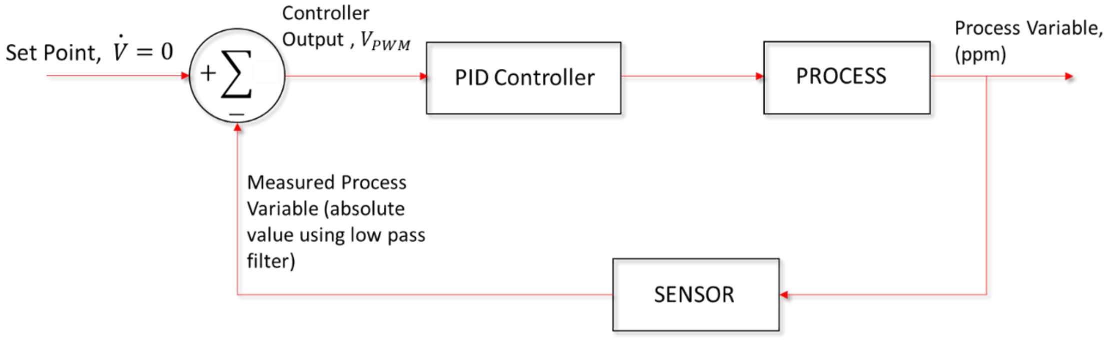

Figure 1. Block Diagram of the System

IOP Conf. Series: Materials Science and Engineering **370** (2018) 012042 doi:10.1088/1757-899X/370/1/012042

2.2. System Hardware
The system includes a set of submersible water pumps, piping network system, sensoring unit (electrical conductivity, pH and temperature) from dfrobot, RF95W LoRa wireless module, controller unit (Arduino mega 2560 and Arduino nano), amplifier circuit unit, power supply SPP1272 battery 12V 7.2AH, electronic GPI flow rate digital meter and hydraulic bench. This experimental model was carried out by control of the Arduino based due to the development of wireless instrument on final discharge point. This microcontroller as Table 1 was consider in the system since it is user-oriented dominated such as size and configuration, easy to manipulate, appropriate time constants, broad spectrum tasks to be solved and easier to access through Matlab/Simulink environment [7].

Table 1. Arduino microcontroller model

Specification	**Description**
Processor	ATmega2560
Processor Speed	16MHz
Architecture	8 bit
RAM Memory	256KB
Programming Language	C Variant
Digital Pins	54 (15PWM)
Analog Pins	16 (0-5V)

2.3. Theoretical Summary of consider method
For establish equipment nowadays has a great standards to determine heavy metal ions in laboratory [8]. The most dominant techniques are Inductive Coupled Plasma Mass Spectrometry (ICP-MS), Inductive Coupled Plasma with Atomic Emission Spectrometry (ICP-AES) [9][10], Atomic Absorption Spectrometry (AAS), Atomic Emission Spectrometry (AES), and Cold Vapor Atomic Absorption Spectrometer (CVAAS) [11][12]. These modern methods use optical detection are more selective and sensitive compare to conventional method [13], however there are not convenient for fields work such as batik factories because it require specifically techniques, long time storage, high cost and bulky. Bioanalytical techniques such as nuclei acid through DNA probes also used to trace heavy metal ions [14]. However, this development techniques recently useful for food and clinical application [15]. In general, most literature emphasizes electroanalytical technique for field work instrument development, real-time and online wastewater status due to high performances such as low detection limit, good stability and wide linear response [16][5].

3. Methodology

3.1. Flow Chart
The figure 2 illustrates the project flow chart. It mainly included 3 phase namely perception layer, signal conditioning layer and terminal layer. At perception layer, system will be initiate from a low voltage until the process variable given a stable reading. The system will compute the error, from an error, PID controller will work for necessary voltage signal. At signal conditioning layer, first reading is providing as an analog value. Then, the value will apply smoothing to get an average analog value. Then, the signal will filter using kalman filter and obtain an average kalman voltage signal. These value will give information for terminal display and process variable of the system. At third phase, terminal layer will display the desired information in graphical user interface GUI which is the status of the solution. In this phase, there will be several mathematical formulations, transmission and receiving through wireless and display monitor. The parameter such as existence metal, treatment

efficiency, fixation rate and water quality is decided for output display. A wireless system is adding on the system with aided of graphical user interface. At last, an identification, verification and validation is conducted.

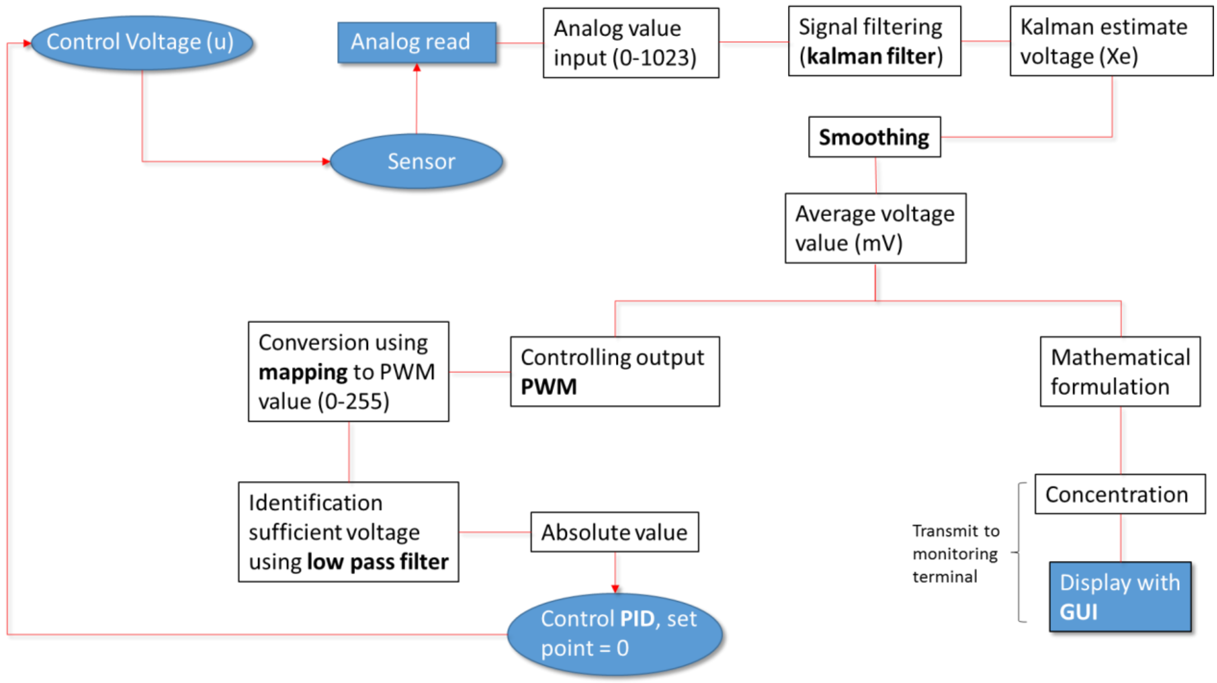

Figure 2. An illustration of whole system

3.2. System Overview

The system uses conductivity sensor. As figure 3, an alternating current (I) was applied at an optimal frequency (typically 94Hz) between two electrodes. The potential voltage between two electrodes will be measured according to ion concentration the solution (V). The resulting voltage is referring also the resistance in the solution. From the measurement of current source and potential voltage, the conductance will be calculated (I/V). Since, cell constant is equal to value of 1, the conductivity value will directly obtain from conductance measurement as written at equation 5.

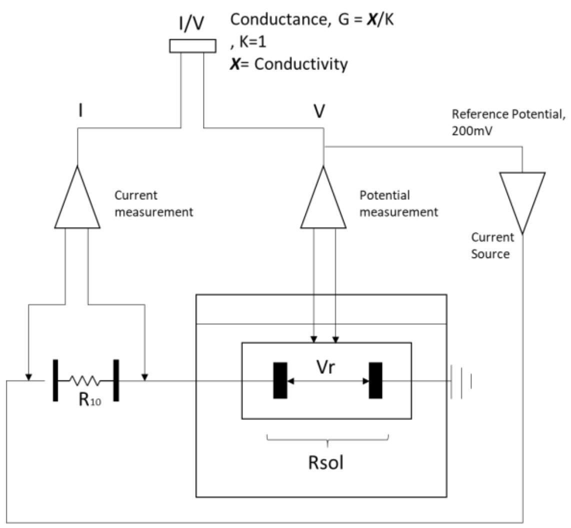

Figure 3. Diagram of the system

3.3. Mathematical Formulation

A current produced in external circuit that connected to the electrodes. This principle follow the ohm's law [17]:

$$E = IR \tag{1}$$

Where E is the applied potential (volt), I is the current measured and R is the resistance of the electrolyte solution between two cell electrodes.

The electrical conductance, G is a reciprocal of solution resistance (S.I units: S Siemens), order literature expressed as mho. However, the measurement of conductance or resistance depends on distance, L between cell electrode and microscopic surface area (geometric area x roughness factor), A of the electrode (A for both electrodes are identical). These parameter can be relate in conductivity formula [18];

$$conductance, G = \frac{1}{R} \tag{2}$$

$$conductivity, \chi = G\frac{L}{A} \tag{3}$$

$$G = \frac{1}{R} = \chi\frac{A}{L} \tag{4}$$

Conductivity is directly proportional to the ratio of distance and area, *L*/*A*. Therefore, in particular measurement and instrumentation, the ratio *L*/*A* is usually constant and rigidly fixed called as cell Constant, (K_c) [19]. Thus,

$$\chi = G\frac{L}{A} = GK_c \tag{5}$$

The transfer function of the measurement circuit will be;

$$V_{output} = \frac{R_{10}(820\Omega)}{R_{solution}}\, x\, |V_{input}| \tag{6}$$

Where $R_{solution}$ is the measurement of resistance in aqueous solution. To conclude, equation is written as;

$$conductivity, \chi = \frac{K_c}{R_{(820\Omega)}x|V_{input}|}\, x\, V_{output} \tag{7}$$

K_c is the cell constant where the value is equal to 1. V_{input} is depend on the signal generating on PWM. Thus, the ion concentration is linear with the output conductivity and given equation as;

$$Ion\ concentration, C\ (ppm) = 6.9887\chi + 1.6167 \tag{8}$$

3.4. Pulse Width Modulation (PWM)

The technique for Pulse Width Modulation is uses an average analog output signal from digital output. The supply signal consists of a train voltages pulses where the width of individual pulses will control the effective voltage level to the system. From the figure 4, it shows the PWM duty cycle where the voltage signal comprised of pulses with duration, τ_0 and it repeat for every τ_c units of time. The digital output from arduino will run maximum at V_s= 5V. Thus, on a PWM pin, the analogWrite an 8-

bit value function will be used to modulate and set the duty cycle. Hence, the effective voltage from analogWrite the value (0-255) that corresponding to signal voltage in range of 0V to 5V. The output voltage are linearly related according to equation 1 [20].

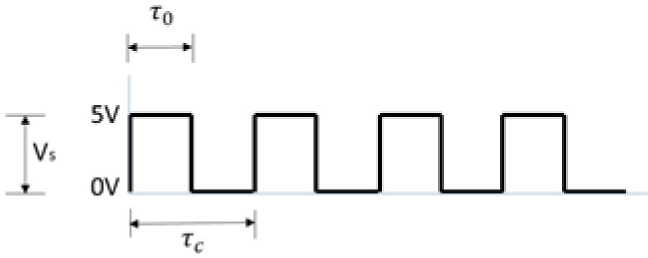

Figure 4. Nomenclature of PWM Duty Cycle

$$PWM\ output = 255\ x\frac{\tau_0}{\tau_c} = 255\ x\frac{V_{eff}}{V_s}, V_{eff} = V_s\frac{\tau_0}{\tau_c} \tag{9}$$

3.5. Sensor Design

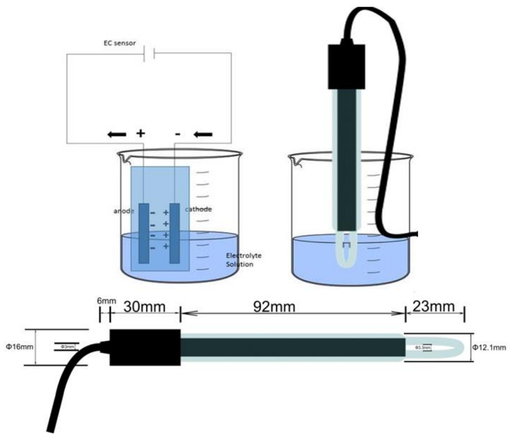

Figure 5. Sensor configuration

Table 2. Sensor specification

Specification	**Description**
Operating Voltage	5V
PCB Size	45mm x 32mm
Operating Temperature	5-40 degree Celsius
Electrode	Electrode Constant K=1
Temperature Sensor	DS18B20 waterproof
Cable length	60cm
PH2 interface	3-pin SMD

4. Experimental Test

To calibrate the conductivity sensor, the calibration plot is used and compare with the calibrate solution. One set measurement data obtained will establish an equation based on least square method. Then, an experimental is set up and the aim for this work is to remove noise from digitization of ADC and random fluctuation signal from the sensor. In this experiment, a synthetic solution with known concentration is prepared as a sample. The sensor (conductivity and temperature) is placed in the container of the sample. The solution will remain static at constant room temperature.

4.1. Signal Filtering

For data acquisition, the performance characteristics figure 6 clearly demonstrates that introduction of Kalman Filter enables to decrease random fluctuation signal. The signal is acquired from the analog value of the sensor. At this moment, smoothing Kalman voltage will give better plot average for particular measurement. With respect to the random character of the process, a comparison running average of Kalman voltage and unfiltered voltage is plotted. When observe the plotting, running average of Kalman Filter represent noise reduction is achieved and influential measurement readings.

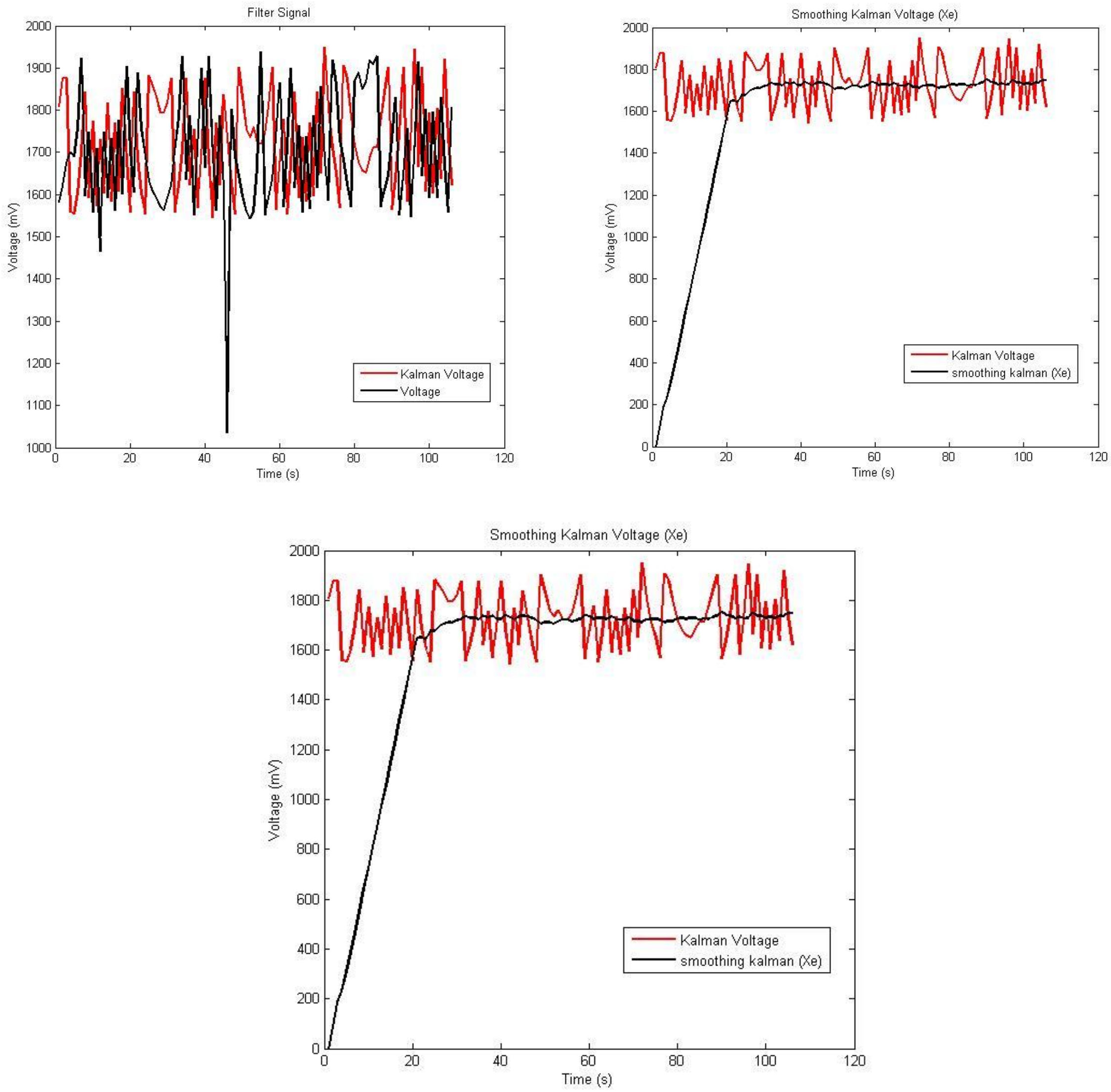

Figure 6. A set of Signal Filtering

4.2. Plot PID Controller

In this section, the PID control is discussed. This controller was applied for making the system enables to select the voltage signal and energize the sensor. As shown in figure 7, three modes for P, PI and PID controller are compared. Set point is set to zero value. The signal will be consider as good performance when approximating to zero value of absolute reading. Since the signal is always fluctuated, it is hard to get zero absolute reading for those signal. However, it is clear in those figures that response PI is better than P and PID mode.

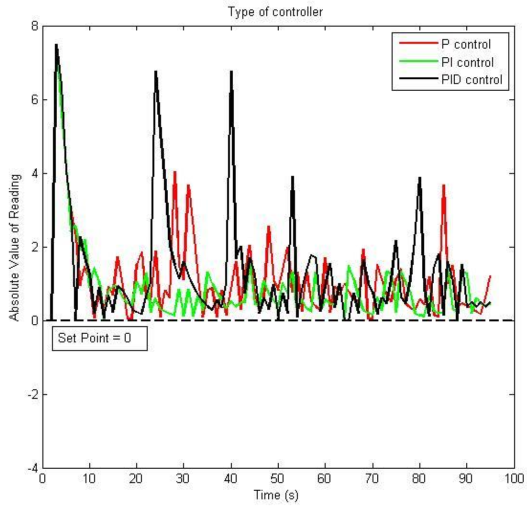

Figure 7. Plots of P, PI, PID modes controller

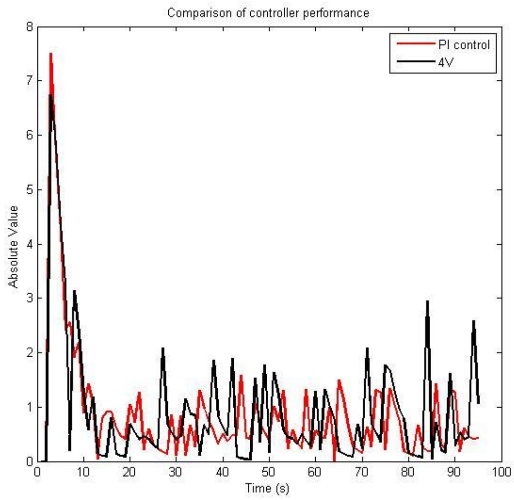

Figure 8. Plots of PI mode controller and Set Voltage

The signals were obtained using the specific instruments. A set number of signals were obtained in static solution and keeping same position of probe. These signals has been through signal filtering by kalman, smoothing and low pass filter where the results led to reduce random signal. The improved signal is then processed using PI control. As shown in figure 8 shows the response of PI control voltage and set 4V voltage. It shows the slightly improvement in controlling the voltage. A series of control measurement of the PI control produce good response with a standard deviation 1.0 and standard deviation for set voltage gave 1.135. The differentiation for two set of measurements has a slightly improvement due to fluctuation voltage energize the sensor. However, the contribution for PI control can be propose at such the voltage supply can be automatically defined sufficiently for reaction occurred.

In figure 9 shows the reading from the sensor response with the time. From the set voltage, Steady State Error SSE is existing for this mode. The systems become unstable with oscillation. When PI controller is applied, ample overshoot is observed, the SSE is reducing and give the voltage signal close to the set point.

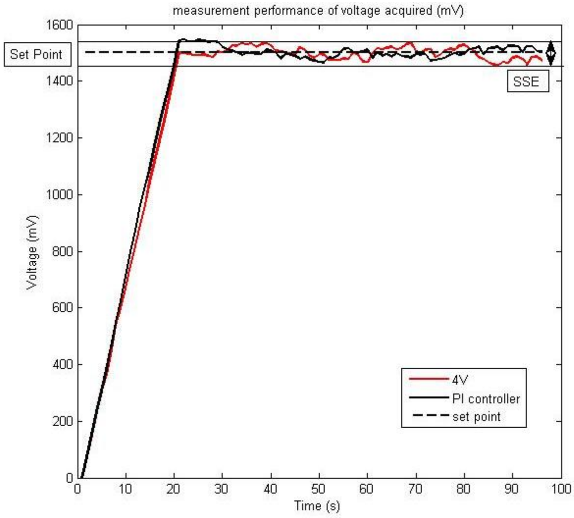

Figure 9. Measurement response of voltage signal from the sensor

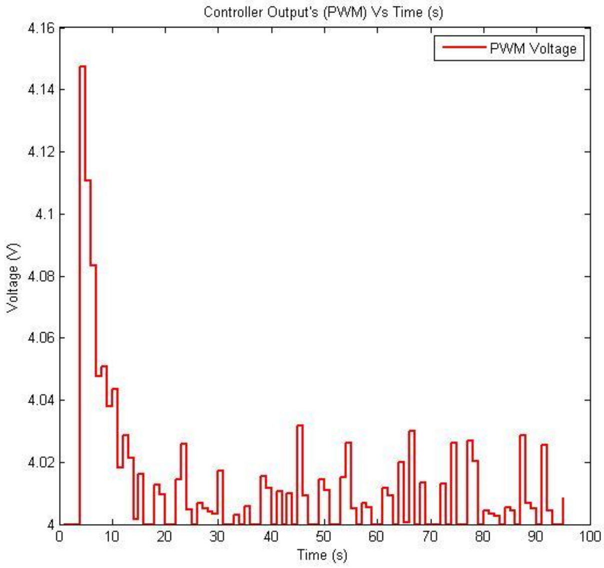

Figure 10. Controller's output VS Time of PI Controller

5. Conclusions

PID controller is designed using manual tuning in experimental work and their performance is compared. It is shown graphically, the controller is essential part and can be implement for the system. With this implement, the system can give voltage sufficiently for a particular reaction. To be conclude, we found that an exact reading for the concentration is difficult due to the digitizing error.

Acknowledgements

This paper was carried out as a part of collaboration program between USM and TUT with transdisciplinary research name “Tools for Heavy Metal Mitigation: Detection and Removal from the environment”. The author would like to thank the USM for funding support through RU Top-Down research grant (1001/PAERO/6740041).

References

[1] F. Al-badaii, M. Shuhaimi-othman, and M. B. Gasim, "Water Quality Assessment of the Semenyih River , Selangor , Malaysia," vol. 2013, 2013.

[2] H. a. Aziz, M. N. Adlan, and K. S. Ariffin, "Heavy metals (Cd, Pb, Zn, Ni, Cu and Cr(III)) removal from water in Malaysia: Post treatment by high quality limestone," Bioresour. Technol., vol. 99, no. 6, pp. 1578–1583, 2008.

[3] S. K. Gunatilake, "Methods of Removing Heavy Metals from Industrial Wastewater," J. Multidiscip. Eng. Sci. Stud., vol. 1, no. 1, pp. 12–18, 2015.

[4] H. Li, A. Shi, M. Li, and X. Zhang, "Effect of pH , Temperature , Dissolved Oxygen , and Flow Rate of Overlying Water on Heavy Metals Release from Storm Sewer Sediments," vol. 2013, 2013.

[5] M. D. Tutulea, I. Cretescu, D. Sibiescu, and C. Stan, "Electrochemical sensors for heavy metal ions detection from aqueous solutions," Environ. Eng. Manag. J., vol. 11, no. 2, 2012.

[6] O. a Farghaly, R. S. A. Hameed, and A.-A. H. Abu-Nawwas, "Analytical Application Using Modern Electrochemical Techniques," Int. J. Electrochem. Sci., vol. 9, no. 2014, pp. 3287–3318, 2014.

[7] M. Huba, P. Bisták, and T. Huba, "Filtered PI and PID control of an Arduino based thermal plant," IFAC-PapersOnLine, vol. 49, no. 25, pp. 336–341, 2016.

[8] Z.-L. Lv et al., "A simplified electrochemical instrument equipped with automated flow-injection system and network communication technology for remote online monitoring of heavy metal ions," J. Electroanal. Chem., vol. 791, pp. 49–55, 2017.

[9] A. Note, "Monitoring Heavy Metals by ICP- OES for Compliance with RoHS and," vol. 2003, 2006.

[10] E. Physics, "ICP-MS DETERMINATIONS OF HEAVY METALS IN SURFACE WATERS Environment is an essential element of human existence . It is a result of interference of natural elements – earth , air , water , climate , biosphere – with elements created by human activity [1]," vol. 57, pp. 1184–1193, 2012.

[11] J. Sanders, "Monitoring Heavy Metals by Atomic Absorption Spectroscopy for Compliance with RoHS and WEEE Directives," Semicond. Anal. Environ. Introd., vol. 1, no. 40, pp. 1–6, 2012.

[12] B. J. Farey and L. a. Nelson, "Atomic Absorption Spectrometry," Tech. Instrum. Anal. Chem., vol. 5, pp. 67–94, 1982.

[13] V. Gayla, "Inductively Coupled Plasma : the Future of Heavy Metals Testing," Life Sci. Tech. Bulletub, no. 17/April, 2009.

[14] J. Wang, G. Liu, and A. Merkoç i, "Electrochemical coding technology for simultaneous detection of multiple DNA targets," J. Am. Chem. Soc., vol. 125, no. 11, pp. 3214–3215, 2003.

[15] M. R. Knecht and M. Sethi, "Bio-inspired colorimetric detection of Hg2+ and Pb2+ heavy metal ions using Au nanoparticles," Anal. Bioanal. Chem., vol. 394, no. 1, pp. 33–46, 2009.

[16] X. Pei, W. Kang, W. Yue, A. Bange, W. R. Heineman, and I. Papautsky, "Disposable copper-based electrochemical sensor for anodic stripping voltammetry," Anal. Chem., vol. 86, no. 10, pp. 4893–4900, 2014.

[17] Sas, "Conductivity-theory and practice," Anal. Radiom., vol. D61M002, pp. 1–50, 2004.

[18] F. Prieto García, E. Barrado Esteban, M. Vega, and L. Debán, "a Rapid Estimation of Metal Contents in Wastewater Treatment for Conductivity Measurements," J. Chil. Chem. Soc., vol. 50, no. 3, pp. 547–551, 2005.

[19] "A Guide to Conductivity Measurement," pp. 6–16.

[20] G. Recktenwald, "1 Basic PWM Properties," 2011.