Development of K500 Signal Processing System using Raspberry PI in the 3-electrodes Electrochemical Sensor

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Abstract. The electrochemical sensor exploits current or voltage on the electrodes when the chemical reaction occurs between the sensitive part of the electrode and the heavy metal ion detected. The output of current or voltage changes corresponds to the amount of ion concentration of heavy metal in water. This research aims to develop signal processing system using raspberry PI as a supporting electronic scheme of electrochemical sensor to detect and analize heavy metal pollutant. The system contains of potentiostat, signal conditioning and data acquisition schemes. This research covers the activities of the design and development of Raspberry Pi based supporting electronic scheme, PCB and the electronic components, as well as the software program for the measurement of signal input from the electrochemical sensor. The performance of K500 system developed in the research is a little bit lower than that of the system published by another researcher. Despite its performance, this system costs only $45 cheaper than previous system that costs $100. For full version, i.e. including Raspberry Pi as a server, the K500 system with the dimension of 110x90x70 mm costs only $70, cheaper than the other system using laptop computer as a server that costs $60 without its server.

1. Introduction

Heavy metal is hazardous pollutant which contaminates human being health as a result of accumulation in environment because it can't be degradated. In normal concentration heavy metal is not too dangerous in water and sedimentation, some heavy metal are required for metabolism of human being in chemical process. But too dangerous if the content is too high and in a long time it can harm in water ecosystem (river, sea, etc.) [1]. Therefore the concentration of heavy metal in water has to be monitored. One of the techniques for heavy metal monitoring is the system of solid electrodes technology integrated into small sensor system based on thick film technology (TFT) [2]. This TFT based sensor system offers low fabrication cost [3]. However, the cost for signal processing is too expensive and the dimension is too big. Meanwhile, Raspberry Pi can be used as a server and microcontroller programing which also offers low component cost and low dimension [4]. Therefore, in this research, we developed the K500, the signal processing system using Raspberry Pi integrated into heavy metal monitoring system. The supporting circuit required to support the performance of 3-electrodes sensor devices is potentiostat. Potentiostat is an instrument to measure potential difference between working and reference electrodes in the electrochemical cell. The working principal of potentiostat is by giving electrical current from working electrode cell to counter electrode cell passing the reference electrode and measuring current difference in the cell [5].

2. Hardware description

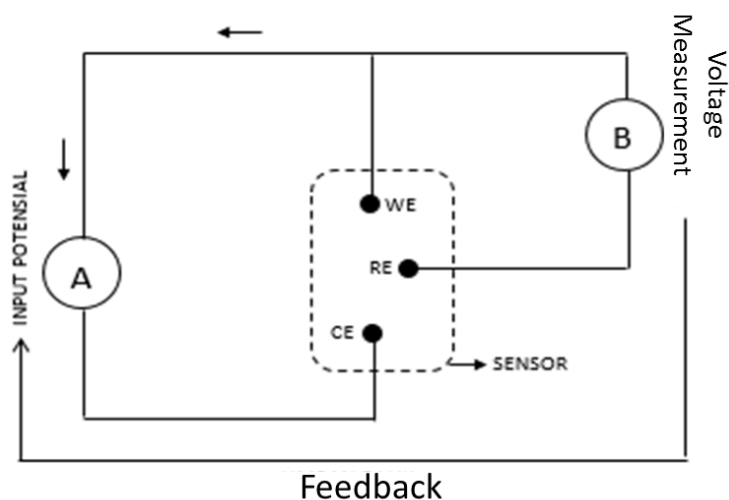The working principal of basic circuit can be seen in Figure 1.

Figure 1. The sensor diagram scheme with 3 electrodes connected between input bias circuits with potential measurement. The controlled variables are the cell potential and the cell current.

The illustration of the diagram of potentiostat working block in this system can be seen in Figure 2.
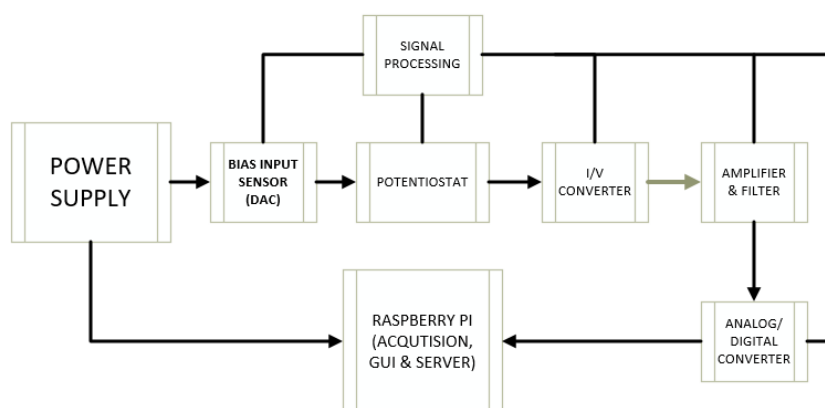

Figure 2. Working diagram block of potentiostat with DAC (Digital/Analog Converter) gives controlled potential input conversion to SENSOR through CONTROL-AMP and the current measurement will be converted by ADC (Analog/Digital Converter) circuit for data acquisition.

2.1. Bias sensor input

The bias sensor input uses IC TLC082N Op-Amp which functions as amplifier with high precision, low bias current, low offset voltage which can be controlled according to the need using IC LM385 as a reference voltage connected with Trimmer Potensio (Figure 3)[6,7].
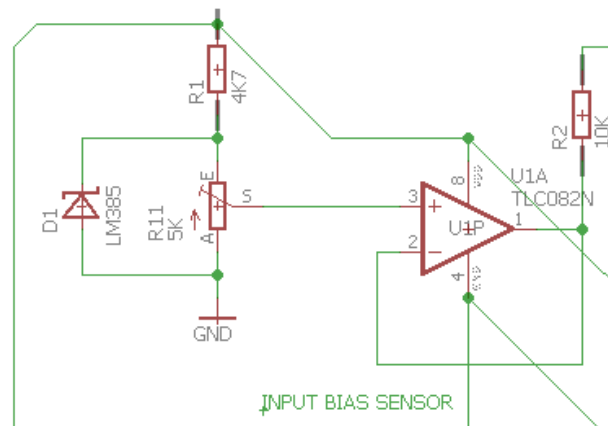
Figure 3. Bias sensor input with IC TLC082N and IC LM385.

2.2. I/V converter

The output of the sensor used is electrical current or called as amperometric sensor. In order to be able to be process by Raspberry Pi the current should be converted into voltage by using IC CA3140AE where the Op-Amp will process the input to be the voltage for output (Figure 4) [8].
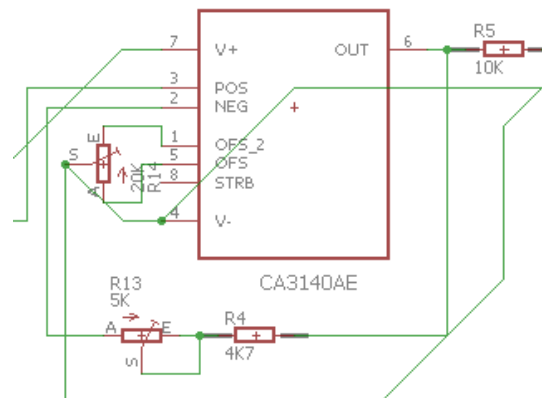
Figure 4. The I/V Converter circuit uses IC CA3140AE where voltage offset can be controlled according to the need with the help of potentio trimmer.

2.3. Amplifier and filter

The current from thick film technology (TFT) sensor of this 3 electrodes is very small, nano scale [2], so the amplifier circuit is required and placed after I/V Converter circuit by using IC TLC081N which has capacity almost the same as IC TLC082N. The difference is only in built-in IC TLC081N [6]. Because the output of IC TLC081N is rough enough so addition of Capacitor 0.01F is required as a filter (Figure 5).
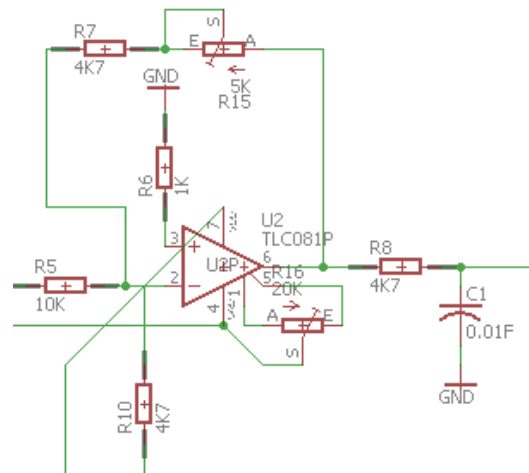
Figure 5. The amplifier circuit with IC TLC081P and addition of capacitor 0.01F as a filter.

2.4. A/D converter

Raspberry Pi only receive input of voltage signal in the form of digital, so the Analog to Digital Converter circuit required by using IC MCP3008 with 10 bit-resolution and technology of Low Power CMOS (Figure 6) [9].
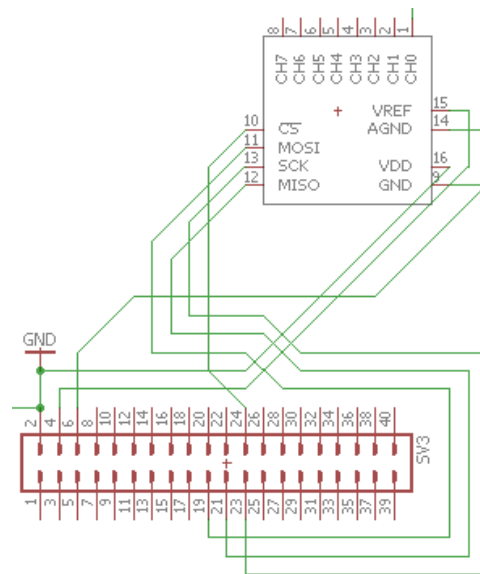

Figure 6. Analog to Digital Converter (ADC) circuit uses MMCP3008 where input channel 0 is obtained from output of amplifier circuit, ADC output is directly connected to GPIO Raspberry Pi 40pin.

2.5. Power supply

The signal processor in this research is made portable using battery 9V with capacity >1.000 mAH for 1 hour operation, because Raspberry Pi consumes ±16 mAH/minute. The voltage required of the signal processor is devided in to two parts that is 9V for potentiostat and 5V for Raspberry Pi. The potentiostat input is based on maximum input voltage every IC [5, 7, 8] and the Raspberry Pi input is based on datasheet [10]. Therefore IC LM7805 is required as voltage regulator 5V [11] and in Figure 7 is found ICL7660 as simple voltage multiplication (Vout=(-)nVin) [11, 12].
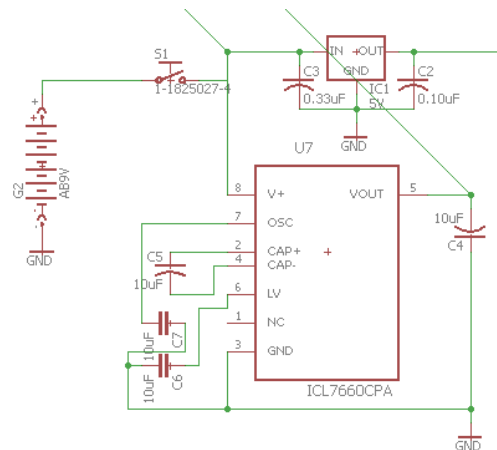
Figure 7. Power supply circuit with supply battery 9V (G2) and multiplication of voltage with ICL7660 and voltage regulation 5V using IC LM7805 (IC1).

2.6. Raspberry Pi

The Raspberry Pi used in this research is Raspberry Pi 3 Model B which has more working process speed with processor 1.2GHz Cortex-A53 compared with previous version using processor 900MHz Cortex-A7. Raspberry Pi 3 is even more efficient in power consumption because in idle condition Raspberry Pi 3 is more efficient 22% than Raspberry Pi 2. The advantages which must required is the built-in wifi feature in Raspberry Pi 3 to facilitate the monitoring process of this research [10].

3. Production operation

The production operation of the hardware in this research covers:

3.1. Circuit simulation

For the circuit simulation before the production of PCB layout, the researcher applies NI Software.

3.2. The schematic design and PCB board

The schematic desain and PCB layout applies the help of CadSoft Eagle Ver.7 software, meanwhile the 3D product model applies Google Sketch Up 2017 which can be seen in Figure 8 & 9.
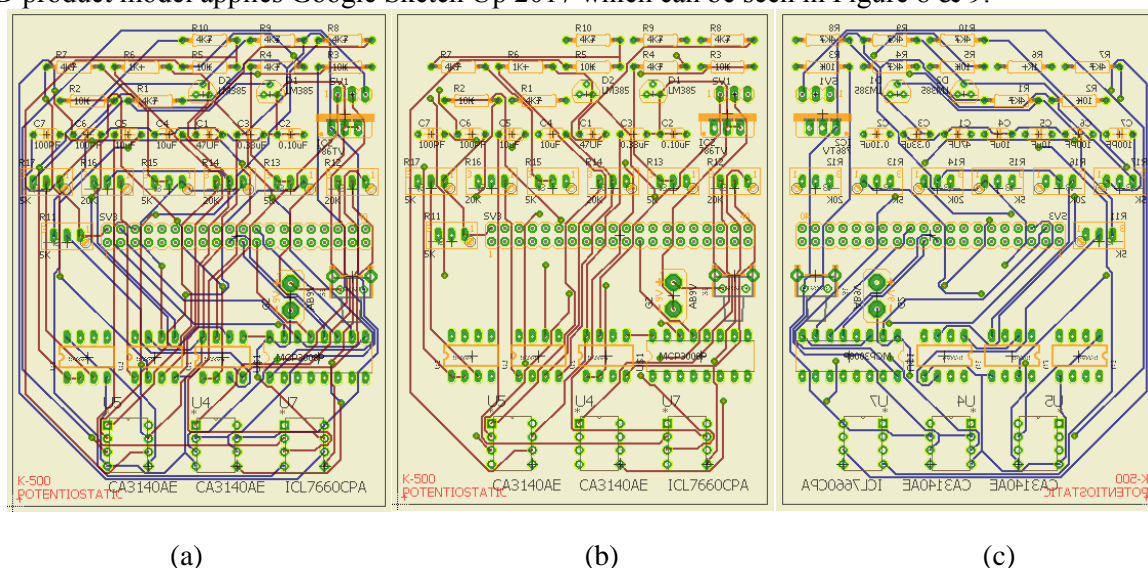

| (a) | (b) | (c) |

Figure 8. Complete schematic design of PCB (a), Front schematic design of PCB (b), Back schematic design of PCB (c).
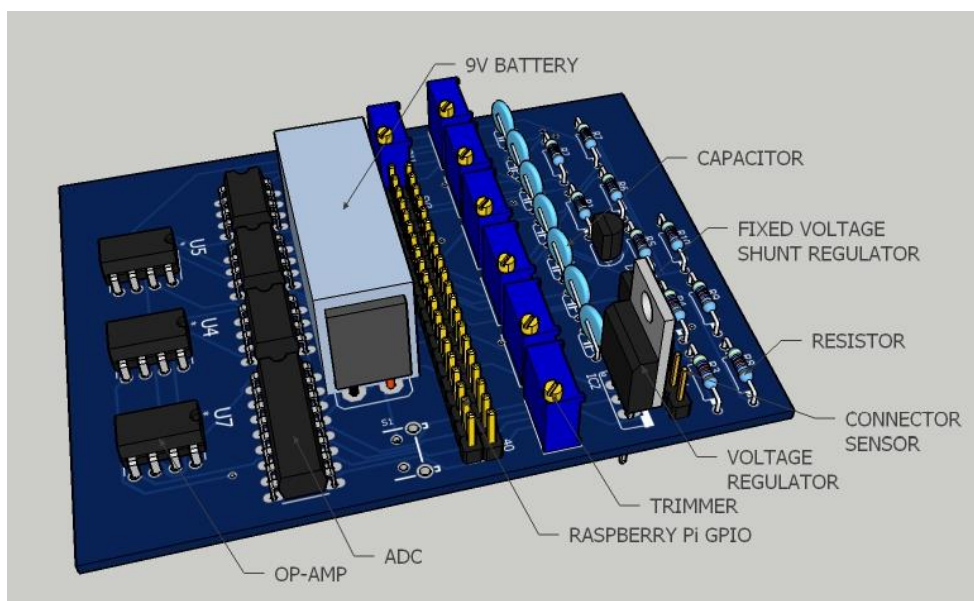
Figure 9. 3D model PC.

3.3. Communication
The communication required from potentiostat to Raspberry Pi applies Phyton programming which can be accessed online in https://learn.adafruit.com/raspberry-pi-analog-to-digital-converters/mcp3008GUI.

3.4. GUI
Graphical User Interface (GUI) which researcher produces has simple interface with Phyton3 base. As for the assisting software for data acquisition such as Numpy and Scipy, for real-time plot applies PyQtGraph and for interface applies PyQt which can be accessed on their official website for tutorial [13-16].

4. Examination and results
For the physical form of potentiostat hardware can be seen in Figure 10 and for examination the device already design and made in this research should be compared with the existing device and internationally recognized. The researcher compares his research result with research result of T. Dobbelaere in HardwareX about "USB-controlled potentiostat/galvanostat for thin-film battery characterization" in the characteristic of cyclic voltammetry (Figure 12). Therefore the measurement technic has to be the same using "dummy cell" as replacing electrochemical sensor, where the dummy cell consist of resistor 1000KΩ and capacitor 1000μF which is set serial and connected from port WE to port RE/CE (Figure 11). The above measurement is based on 1st orde differential equation:

$$I = \frac{U_R}{R} = C\frac{dU_C}{dt}, U = U_R + U_C \tag{1}$$

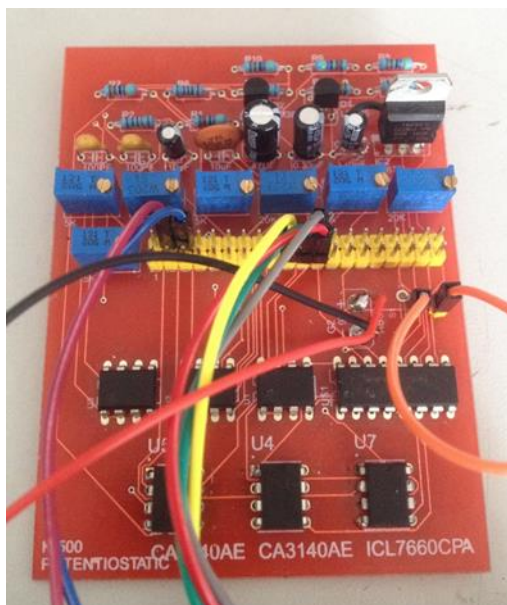It usefull to verify potentiostat measurement by comparing the potential value to the result expected.
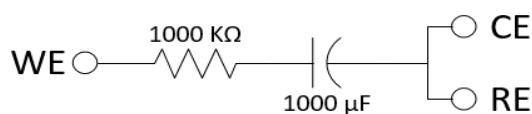
Figure 10. Potentiostat hardware.

Figure 11. Dummy cell schematic.

Figure 12. The result of cyclic voltammetry graphic, the result which is not too far can be considered that the device made has good performance.

Although the performance of K500 is a bit under the performance of T. Dobbelaere it can be concluded that k500 has a good performance, economically k500 is cheaper where the production cost of K500 is under 45$ compared with T. Dobbelaere which costs almost 100$ [17]. From point of full

version (including server) this research is even more excellent because the role of Raspberry Pi as a server with total cost about 70$ and with the dimension 110x90x70 mm including server, compared to Dstat, Emstat and Cheapstat which still uses laptop as a server and costs over 60$ excluding server [18].

5. Conclusions
The performance of K500 system developed in the research is a little bit lower than that of the system published by another researcher. Despite its performance, this system costs only $45 cheaper than previous system that costs $100. For full version, i.e. including Raspberry Pi as a server, the K500 system with the dimension of 110x90x70 mm costs only $70, cheaper than the other system using laptop computer as a server that costs $60 without its server.

As the design is made open source and not many newest precision components are available in local market, there should be a special modification to process electrochemical signal sensor with new method. The limitation in this journal is that not all the result and the process can be presented due to the number of pages stipulated by the publisher, so for more information please contact the researcher through enclosed email above. New experiment in python programming is really needed to maximize calculation, GUI, and also performance of the device used in this research.

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