Engineering Innovations
ISSN: 2813-1002, Vol. 12, pp 49-54
doi:10.4028/p-r0bO0I

Submitted: 2023-11-14
Revised: 2024-04-30
Accepted: 2024-05-08
Online: 2025-01-03

Fabrication of a Potential Difference Measuring Instrument Using a Capacitive Sensor Based on aTmega328 Microcontroller

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Keywords: ATmega328; Arduino; Capacitive sensor; Potential difference; PLX-DAQ.

Abstract. A potential difference-measuring instrument using a capacitive sensor based on ATmega328 microcontroller has been successfully designed and implemented. The instrument consists of 2 (two) silver plates as electrodes, INA219 module, Arduino Nano module, LM 2596 module, Organic Light-Emitting Diode (OLED), and 9V 1A (DC) adapter. The electrolyte solution used was KCl solution. The basic principle of the instrument is that the adapter is the input, the electrolyte solution is the source of electrical energy, and the capacitive sensor is the electrode, namely the anode and cathode. The input data is processed by Arduino Nano ATmega328, and the output data is displayed on OLED and automatically saved with format .xlsx. The instrument has been calibrated with a standard electrode, namely the Hanna HI 5414 reference electrode, with an accuracy of 99.82%. The result indicates that the instrument can be used to measure membrane potential, which replaced the measurement manually.

Introduction

The development of increasingly advanced technology and information is also followed by many developments in increasingly advanced instruments, one example of which is an electric meter. This instrument is made to make it easier for users to use it, such as in the field of education, for example, electric potential difference experiments. Measurement of potential difference using a voltmeter with two electrodes as conductors, namely the anode and cathode with an electrolyte solution as a source of electrical energy. In electrolyte solutions, positive ions and negative ions will move and collect on the electrode surface [1].

Several studies on membrane potential differences have been carried out, including the influence of UV-C radiation exposure time on ion characteristics and diffusion current density in chitosan membranes [2], the influence of various types of salt on the potential difference of chitosan membranes [3], the influence of electrolyte solutions on ion transport in chitosan membranes [4], and curve studies current-voltage (I-V) characteristics of silver-chitosan nanoparticle composite membranes [5]. In this research, potential difference measurements were carried out using a multimeter and the results of potential difference measurements were recorded one by one. This method of measurement is inefficient and less effective.

Therefore, in this research a potential difference measuring instrument was design and made using capacitive sensor based on ATmega328 microcontroller. Potential difference measurements will be more effective and easily carried out with a digital system, namely using capacitive sensor by using two silver plates connected to INA219 module. The output of this module is received by ATmega328 microcontroller and processed according to the program that has been made in Arduino Integrated Development Environment (IDE) software and measurement results displayed on Organic Light-Emitting Diode (OLED) and Microsoft Excel.

The capacitive sensors are usually made of copper, silver, platinum and gold plates by working on the basis of electrical charges that received by the sensor due to changes in plate distance and changes in cross-sectional area with electrolyte solutions as a source of electrical energy. Electrolyte solutions are solutions that conduct electric current [6].

Capacitive sensors can respond to and evaluate changes in the physical or chemical properties of a material through variations in capacitive values associated with sensor geometry modifications (such as the distance between two capacitor plates/electrodes, overlapping surface area) or the dielectric material (permittivity) [7]. Recently, capacitive sensors have become increasingly popular due to their versatility and suitability for simple and low-cost measurements [8]. Differential capacitive sensor is a type of transducer that shows better rejection of common mode interference for cases of low capacitive variation [9]. Differential capacitive sensors are widely used as position sensors and accelerometers [10, 11].

Ion transport across a membrane is a process of moving ions from one chamber to another; this occurs through passive and active transport processes. Each chamber contains the electrolyte solution, which is separated by a membrane and has different concentrations, so according to Fick's law of diffusion, ions from a high concentration will move across the membrane toward a lower concentration. The ions flow affects the flow of electric current in the membrane. The magnitude of the current is related to the voltage and the difference in concentrations of electrolyte solution [12].

The INA219 module is connected to a capacitive sensor so that the INA219 functions as a sensor on the instrument to read DC voltage from the source [13]. Data from the INA219 sensor is processed by Arduino Nano module. Arduino Nano is the brain of the instrument system controller [14]. The processed data is displayed on an Organic Light-Emitting Diode (OLED). OLED is a display with 8 lines per page and 128 pixels per line. Also, it is required LM 2596. The LM 2596 is a step-down module that converts the DC input voltage to DC voltage. Program writing is done with the help of Arduino IDE which is embedded in the Arduino microcontroller.

Methods

a. System design. The design of the potential difference measuring instrument is shown in Fig. 1.

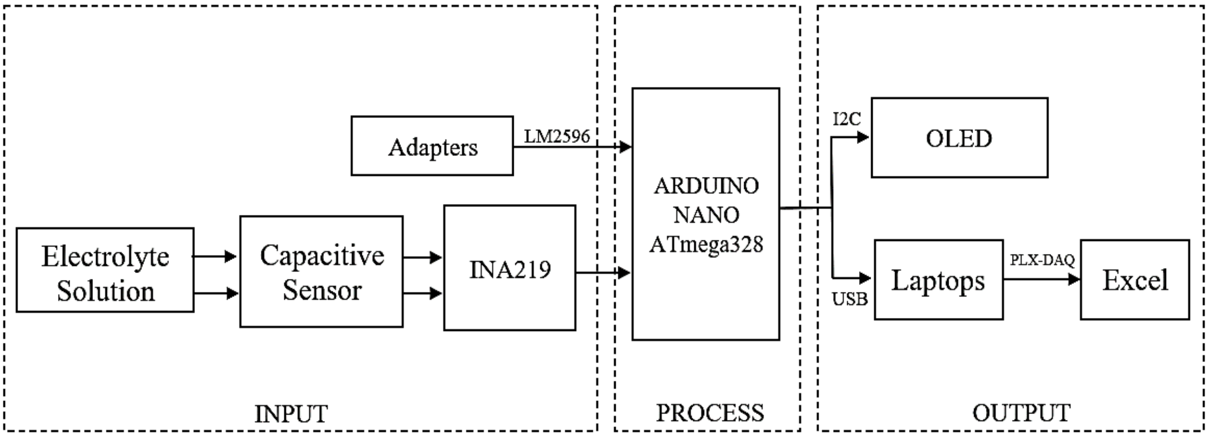

Fig. 1. The block diagram of the instrument made.

Figure 1 shows that the input block consists of an adapter that functions as a voltage source for the Arduino Nano module, a KCl electrolyte solution as a source of electrical energy, and a capacitive sensor as an electrode, namely the anode and cathode, which is connected to INA219. The input data will be processed from analog to digital signal by Arduino Nano. The output data is displayed on OLED via I2C and saved in Excel format .xlsx.

b. Calibration method. The calibration is carried out by determining the relationship between the measurement data of the instrument made and the measurement results using a standard electrode. The standard electrode used is the Hanna HI 5414 reference electrode. This relationship is expressed by the regression equation Eq. (1).

$$Y = \mathrm{a}X \pm \mathrm{b} \tag{1}$$

Where Y is the response variable, X is the predictor variable, a is the regression coefficient, and b is the constant. Furthermore, from Eq. (1), the calibration equation can be determined, namely Eq. (2).

$$Y' = \frac{Y \pm \mathrm{b}}{\mathrm{a}} \quad (2)$$

Where Y' is the calibrated voltage, Y is the sensor reading, a is the regression coefficient, and b is a constant. Next, Eq. (2) is embedded in the program code of the instrument made, so that the measurements obtained show conformity with the instrument standard.

Result and Discussion

a. Result. It has been successfully designed and made a potential difference measuring instrument by using a capacitive sensor based on the ATmega328 microcontroller. The instrument consists of 2 silver plates, an INA219 module, an Arduino Nano module, an LM 2596 module, an Organic Light-Emitting Diode (OLED), and a 9V 1A (DC) adapter, as shown in Fig. 2.

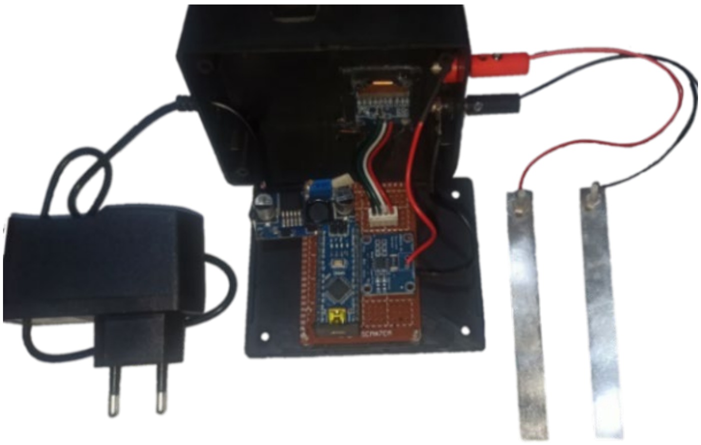

Fig. 2. The potential difference instrument made.

b. Discussion. The calibration was carried out at a set point of volume in the range of 5 to 15 mL with an increase of 0.1 mL at each set point and at a distance between the two electrodes of 3 cm. The calibration result data is shown on the calibration chart in Fig. 3.

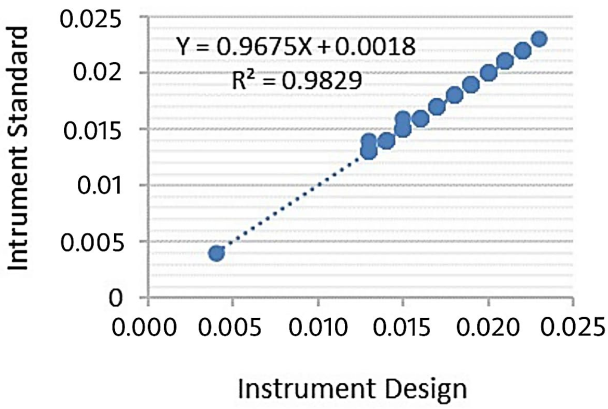

Fig. 3. The calibration graph of the instrument made.

Figure 3 shows an equation with regression coefficient of 0.9675, a constant of 0.0018 and a coefficient of determination (R^2) of 0.9829. The coefficient of determination indicates that the accuracy of the instrument made is 98.29%. This shows a deviation of measurement between the instruments made and the standard one. So it is necessary to do more measurements to recalibrate the measuring instruments made, and then adding the calibration equations to the program code. The data obtained are displayed on the calibration graph as shown in Fig. 4.

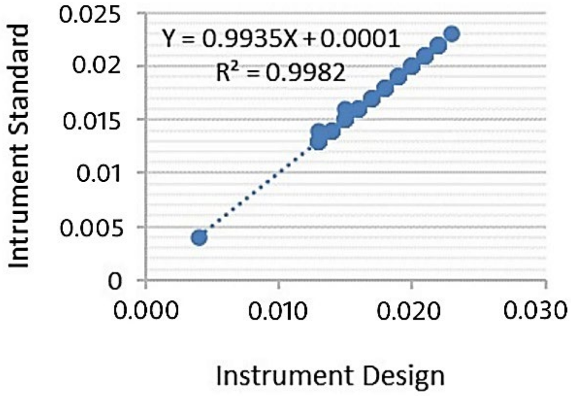

Fig. 4. The recalibration graph of the instruments made.

Figure 4 shows an equation with a regression coefficient of 0.9935, a constant of 0.0001, and a coefficient of determination of 0.9982. The coefficient of determination obtained shows that the accuracy of the measuring instrument made is 99.82%. The accuracy was increased by 1.53% compared to the previous accuracy. Further, the measuring instrument was used to measure the membrane potential of '2% chitosan membrane' in various concentrations of KCl electrolyte solution. The data obtained are presented in Table 1.

Table 1. The potential difference data of '2% chitosan membrane' in various concentrations of KCl electrolyte solution.

Concentration (mM)		Average Voltage (V)	
Room 1	Room 2	Design*	Standard**
0.1	0.1	0.0026	0.0026
1	0.1	0.0068	0.0068
10	0.1	0.0080	0.0080
100	0.1	0.0106	0.0106
250	0.1	0.0116	0.0116
500	0.1	0.0168	0.0170
750	0.1	0.0176	0.0176
1000	0.1	0.0186	0.0186

* = the instrument design; ** = the standard instrument.

Table 1 shows the similarity reading results obtained between the measuring instruments made and the standard one. This shows the accuracy of the measuring instrument made. It was also found that the measuring instrument made has several advantages compared to the standard one including, a shorter measurement time required of around 30 minutes, while the standard instrument requires around 100 minutes. The data obtained is automatically saved in excel data format (.xlsx), which is very necessary for the next analysis. Meanwhile, the measurements by using the standard instrument were one by one manually. Table 1 also shows that the greater the difference in solution concentration between the two rooms, the greater the potential difference generated. These results are consistent with published studies. So this result indicates that the instrument made can use to measure membrane potential which replaced the measurement manually.

Conclusion

In this research, it is reported that a potential difference measuring instrument has been successfully designed and manufactured using a capacitive sensor based on the ATmega328 microcontroller. The measuring instrument consists of two (2) silver plates as electrodes, an INA219 module, an Arduino Nano module, an LM 2596 module, an Organic Light-Emitting Diode (OLED), and a 9V 1A (DC) adapter. The workings instrument procedures are adapter and KCl electrolyte solution as a source of electrical energy, capacitive sensors as electrodes called anode and cathode, which are connected to INA219. The input data is processed from analog to digital signals by Arduino Nano, and the output data is displayed on the OLED via I2C and saved in Excel format. This instrument has an accuracy of 99.82%.

Acknowledgment

The author would like to thank all those who have assisted in the research work, especially the Head of the Biophysics Laboratory and the Head of Dept. of Physics, Faculty of Mathematics and Natural Sciences Udayana University, who have provided facilities to conduct this research.

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