Low-cost multi electrode resistivity meter based on microcontroller for electric resistivity tomography purpose

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Abstract. This study was conducted to make Multi Electrode Resistivity Meter with simple and low-cost circuit design. The instrument that has been made use switching mode boost converter for increasing the voltage with Arduino Nano as a source of PWM signal connected to the boost converter circuit, and cascode current mirror circuit is used for constant current source. The sensor on this resistivity meter using the voltage divider circuit for voltage sensor, and non-inverting OPAMP circuit for current sensor. Multi electrode circuit using relay module connected with IC74HC595 and controlled by Arduino MEGA 2560. This instrument is integrated with GUI that serves as controller and data display. There are several measurements for this instrument that is maximum resistance on each constant current generated from the circuit, repeatability and reproducibility measurement, sensor calibration measurement, and ERT measurement with three configuration i.e wenner configuration, wenner-schlumberger configuration, and dipole-dipole configuration on soil samples.

1. Introduction
Resistivity Method often used for geophysics exploration because have simple physical principle and efficient data acquisition [1]. This method using different resistivity value for discover type of soils or rocks beneath earth surface. The principle of this method is using electric current and injecting it to the soil, and measure voltage from the soil, from that two variables then obtained resistivity value [2].

There are several researches using resistivity method for detects abandoned underground mine [3], research for long-term CO$_2$ monitoring [4], for investigating landslide [5], and research using multi-electrode resistivity method for gravel prospecting [6]. This method usually used for searching ground water, civil technics and for environment problem.

Resistivity Method have some configuration is used, for example resistivity sounding, profiling, tomography, and imaging [7]. This method can be used for measure resistivity value in one dimension to three dimension. Generally, resistivity method on geophysical exploration using 4 point probe configuration, with two electrode for injecting the current, and the other two for measure the voltage [8].

There are several resistivity-meter for this method that have a quite expensive price. Several studies that has succeeded in making resistivity meter such as the design of resistivity meter with constant current source of 0.1 mA and 1 mA [9], research on relay-based multi-electrode resistivity meter [10], and research about inexpensive resistivity meter for groundwater exploration [11]. In making this
resistivity meter, there are several circuits used such as cascode current mirror, boost converter circuit, relay circuit, current and voltage sensor, arduino as microcontroller with GUI made using Processing Open Source Software.

The aim of this study was to create an arduino-based multi-electrode resistivity meter with cheap component prices. Data taken in this research is maximum resistance value for the current generated by the resistivity meter remains constant, repeatability and reproducibility of resistivity meter, and constantly generated electric current, voltage, variation of electrical resistance, and apparent resistivity value.

2. Methods
In this article, the resistivity meter uses four core circuits. The first circuit is a boost converter circuit, second circuit is cascode current mirror circuit, the third circuit is voltage and current sensor circuit, and the last circuit is multi relay based electrode circuit. This tool is able to release a constant electric current that can be adjusted using a potentiometer, and measurable data is displayed on the GUI.

The first step begins by making a boost converter circuit for raise the voltage from 12 V to 125 V. This circuit utilizes inductors and MOSFETs that function as a switch. The circuit will have two states: Continuous Conduction Mode (CCM), and Discontinuous Conduction Mode (DCM) [12]. The two states will change according to the Arduino Nano PWM signal cycle connected to the Gate MOSFET. After that, a constant current generated by using the cascode current mirror circuit [13]. This circuit is connected directly to the boost converter circuit. The circuit is made by connecting four BUV106 transistors with the NPN type. Furthermore, the voltage and current sensors were made using a voltage divider circuit for the voltage sensor[14], and the non-inverter amplifier circuit for current sensor [15]. The next step is to make a relay based multi-electrode circuit regulated by IC 74HC595 which is used to transfer binary data from the Arduino[16]. And the last step is to create GUI using Processing software.

![Electrode Array](image)

**Figure 1** The design of multi-electrode resistivity meter

The first data retrieval is the maximum resistance generated at the 5 mA and 10 mA current of the measuring instrument is performed by rotating the potentiometer in the current mirror circuit. After that, measure the voltage and current value with 10 minutes time interval and data retrieval every 10 seconds, and then measure the same current and voltage on the next day. The last data retrieval is measuring the apparent resistivity value with two arrays, Wenner array and Wenner Schlumberger array.
3. Results and Discussion
Have done the research and manufacture of multi-electrode resistivity meter based on the Arduino microcontroller for electric resistivity tomography surveying. The measuring instrument is made using Ohm's Law principle that the electric current flowing from one point to another will be directly proportional to the voltage value and inversely proportional to the resistance to the conductor in which the electric current flows. Some of the soils and rocks properties can be determined by measuring the electrical properties, one of which resistivity. The resistivity is kind of a material barrier electrified. This measuring instrument will measure the value of soils or rocks resistivity by flowing electric current on the surface of the earth and measured the value of the voltage that arises.

![Figure 2 Resistivity meter made in this research](image)

There are four electrodes used to measure resistivity. The two electrodes serve to flow the electric current and the other two electrodes will serve to measure the voltage caused by the electric current. This resistivity meter uses a multi-electrode system that is automatically controlled by Arduino. In addition there are other important circuit such as boost converter circuit, current mirror circuit, sensor circuit, and multi electrode controller circuit based on relay. Boost converter circuit will supply electricity energy to the measuring instrument so that measurements can work. When the voltage has been raised, then forwarded to the constant current mirror circuit. After that, the electric current flows into the multi-electrode circuit and then flows to the soil surface.
The making of measuring tools is done by programming microcontroller using Arduino IDE and Processing as GUI program which is useful in data acquisition of soil samples. This GUI will display a table of data acquisition such as the coordinates of each electrode, voltage and current values are measured, the value of the geometry factor and resistivity values. Within the GUI, there are buttons that are useful to determine the configuration of the electrodes and useful text box spaced electrodes. The results of the data acquisition will be saved into a file comma-separated values (.csv).

Maximum resistance measurements were made by varying the two constant current values, i.e., 5 mA, and 10 mA. The result of the measurement is then made a graph of the relationship of resistance and current.

**Figure 3** Graphic User Interface (GUI) which are made with Processing Software

![Resistivity-Meter Controller V1.00](image)

**Figure 4** (a) Graph of the relationship between resistance and current at 5 mA constant current (b) Graph of the relationship between resistance and current at 10 mA constant current

From the graph (a) it is found that a maximum resistance of 14000 Ohm at a constant current of 5 mA. At 15000 Ohm, the current decreases significantly to 4.5 mA. And from the graph (b), the maximum resistance at 10 mA constant current is at 6500 Ohm. The value is smaller than the maximum resistance value at a constant current of 5 mA. At the 10000 Ohm resistance, the current begins to decrease to 5 mA, when close to value 12000 Ohm, the circuit stops producing an electric current.
Figure 6 (a) Repeatability and Reproducibility of current (b) Repeatability and Reproducibility of voltage

The average current obtained in the measurement on Graph (a) is $8.87 \pm 0.203$ mA for day 1 and $9.145 \pm 0.055$ mA for day 2, with an accuracy of 97.70% and 99.39%. The average voltage obtained in the measurement on graph (b) is $4.427 \pm 0.130$ mV for day 1 and $4.367 \pm 0.070$ mV for day 2, with an accuracy of 97.70% and 98.37%, from both of the graph, data trend on both day is the same, and the value is not much different.

The last step is done taking soils apparent resistivity data with laboratory scale. Measurements were made by measuring soil samples using multi-electrode resistivity meter that have been made and also measured using the OYO Resistivity-meter MchOhm as a comparison device. Measurements were made with two different array of Wenner, and Wenner-Schlumberger array.

Table 1 Apparent resistivity from instruments and apparent resistivity from OYO (Wenner Array)

| $\rho$ Multi-Electrode Resistivity meter ($\Omega$m) | $\rho$ OYO ($\Omega$m) |
|-----------------------------------------------|---------------------|
| 35,738                                        | 25,982              |
| 37,801                                        | 27,109              |
| 33,9229                                       | 33,171              |
| 185,863                                       | 28,039              |
| 47,0445                                       | 28,386              |
| 103,001                                       | 90,892              |
| 92,901                                        | 83,960              |

Table 2 Apparent resistivity from instruments and apparent resistivity from OYO (W-S Array)

| $\rho$ Alat Ukur ($\Omega$m) | $\rho$ OYO ($\Omega$m) |
|----------------------------|---------------------|
| 34,006                     | 25,880              |
| 37,348                     | 28,904              |
| 32,839                     | 34,885              |
| 185,442                    | 28,252              |
| 38,134                     | 29,643              |
| 97,437                     | 68,311              |
| 107,860                    | 78,984              |
| 629,059                    | 61,250              |
| 14,936                     | 132,789             |

From the data obtained on the measurement using the Wenner array, there is a difference in the apparent resistivity value of the type on resistivity meter with OYO. The difference is seen in the apparent resistivity value of the measuring instrument 10 Ohm-m greater than the measured resistivity.
value measured using OYO. In the measurement with the Wenner-Schlumberger array, the difference in the apparent resistivity value in the measuring instrument remains larger than 10 Ohm-m compared to the data obtained using OYO.

In conclusion, the resistivity meter have been created to have maximum work resistance for 5 mA current of 14000 Ω and 10 mA of 6500 Ω. The voltage sensor has an accuracy of about 97% to 99%. In the soil resistivity measurement, there are still some data with the same trend but have different values than the measurement with OYO MchOhm tool.

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