Design of digital resistivity-meter for subsurface exploration

Maison*, K.N. Sawitri, Samsidar, L. Handayani, R. Purbakawaca, and J. Nurjaman

Department of Physics, Universitas Jambi Jl. Raya Jambi-Ma. Bulian KM 15
Indonesia 36361

*email: maison@unja.ac.id

Abstract. Subsurface exploration is continuously running like increasing energy demand. Many explorations using analog resistivity meter as the measurement tool. The problem faced by users when using this tool is the lack of time efficiency and a high measurement error. We have to write manually the data which is shown on display. From all current and voltage, only the maximum one is needed. So the user needs to pay high attention to data fluctuation. This research aimed to design digital resistivity meter using current sensor and microcontroller Arduino UNO. The data then converted and saved into an SD card. The user can easily operate the system from the dashboard and touchscreen display. The device was calibrated to analog resistivity meter Nafouri NRD-300 which was sold commercially. We can get the comparison of usage, precision, and efficiency between the digital and analog resistivity meter from calibration. The results of the calibration will be discussed.

1. Introduction

Indonesia is known as a country with the huge amount of natural resource, not only the biological but also kinds of mine products such as oil, tin, copper-nickel, bauxite, coal, gold, silver and many more. This natural wealth due to geology and astronomy factor, also the fact that Indonesia is a maritime country.

Theoretically, massive natural resources are beneficial to support the economic system and the prosperity of a country. But it can happen only if they are managed well. There are so many methods of science that can be used to explore natural resources and energy owned by Indonesia. One of the branches is geophysics. It is the knowledge used to learn about the condition of the bottom side of the surface by applying the physics principles. One of the methods that can be applied in geophysics application is geo-electricity.

In applying geoelectricity method, the tool used is resistivity meter. It can be functioned to find out the resistivity under the surface. Unfortunately, it costs a lot of money. The system of resistivity meter is quite simple, just based on Ohm Law. It injects current (I) and then will be able to read how big the potential difference (V). As a result, the (ρ) can be measured [1,2]. Then, the resistivity can be used to predict the condition under the surface. There are so many benefits of this tool, to discover the layers of rock under the surface until approximately 300 meters in depth, to detect the layers of mine, to predict the geothermal energy, and to measure groundwater aquifer [3]. In some locations, the unsuccessful exploration of the natural resources and energy is caused by the lack of information about the exact spot of it.

The development of the gravity tools for measuring soil characteristics on drought mapping land [4] has mapped to improve soil stability. The geo electric method as a tool to characterize the
distribution of gravimetric water in a landfill [5]. There are two types of measurements in the resistivity-meter, namely Horizontal Profiling (HP) and Vertical Electrical Sounding (VES), the vertical and horizontal distribution of the measurement is called the geo electric cross section [6].

Furthermore, the geo-electricity tool usually still uses manual analysis that takes a very long time. In every measurement point, the team has to write manually about how big the current injected, potential difference read, and the resistivity is. All of those activities spend a lot of time because, in one exploration, the data that should be taken are from hundreds of measurement point. Based on the reason above, the calculation of acquisition data should be digitalized.

2. Theoretical Framework

2.1. Geo electrical Method

Geo electricity is one of the geophysics methods studying the character of electricity flow deep inside the earth and how to detect it from the surface. The method works by knowing the resistivity change of the rock layers under the surface. DC (Direct Current) with high voltage will flow inside the soil. This injection uses two electrodes, A and B plugged into the soil at a certain distance.

The principle of measurement using the geo electricity method is by injecting current (I) (in mA) inside the earth then the potential difference (V) that occurs (in mV) is measured through two electrodes. The apparent resistivity value (\( \rho_a \)) from the calculation of current and potential difference for every distance of the electrodes is got by applying the formula as follow:

\[
\rho_a = k \frac{V}{I}
\]

(1)

K is called a geometry factor. In the geoelectricity method of resistivity, there are so many electrode configurations. They are Wenner, Schlumberger, Wenner-Schlumberger, and dipole-dipole configuration, where each of them is used for mapping or sounding exploration [7,8].

2.2 Apparent Resistivity and Soil Resistivity

In the acquisition data process, the measured resistivity called apparent resistivity (\( \rho_a \)). Our earth consists of layers with different \( \rho_a \). Apparent resistivity is formulated as follow:

\[
\rho = 2\pi \left[ \left( \frac{1}{r_1} - \frac{1}{r_2} \right) - \left( \frac{1}{r_3} - \frac{1}{r_4} \right) \right]^{-1} \frac{\Delta V}{I}
\]

(2)

\[
\rho_a = K \frac{\Delta V}{I}
\]

(3)

Explanation: \( \rho \) = Apparent resistivity (\( \Omega m \)), \( K \) = geometry factor (m), \( \Delta V \) = deviation of potential difference (Volt), \( I \) = current (Ampere) [6].

In interpretation, image acquisition is needed about how big the resistivity is for different kinds of water and rocks or the combination in between generally. Based on the resistivity value of earth materials, the data are served in Table 1.

3. Methods

3.1. Preliminary Survey

The preliminary survey is done to find out about the range of voltage value and current that might happen in the field. Those two ranges will determine how many reinforcements and strong circuit amplifier needed in designing the hardware. The survey is done by giving variations of current injection using existing manual resistivity meter.
3.2. Designing Hardware System

This basis of the step is the current injection principal and noticing the quick change of voltage that is showed through LCD and the data saved in the SD card. The main series of hardware compiler consists of the inverter circuit, voltage source, GPS module, Arduino Mega 2560 system, LCD, LED, RTC, and SD logger circuit as in Figure 1.

![Figure 1. The scheme of hardware.](image1)

Inverter series is used to empower the current from the voltage source by converting DC to AC and back. Pulse width modulation (PWM) in this inverter series is the IC TL494CN. This circuit transforms DC into AC in the first step. In sequence, the AC voltage is empowered by a transistor in and MOSFET IRFZ44. Next, trafo is used to empower until 42V. In the final step, the voltage is turned back into DC 42V through two rectifiers. The scheme of the inverter series is shown in Figure 2.

![Figure 2. Inverter Series.](image2)

The microcontroller used in this resistivity meter is Arduino Mega2560 that has 54 input pin or (I/O) digital output and 16 analog input pin (see Figure 3). The source voltage can be from a USB connection or other external devices. The amount of memory that can be accommodated by Arduino is 256KB with SRAM 8KB and EEPROM 4KB.
The measurement result will be shown by using LCD TFT with capacitive sensor basis. LCD’s pin connected to Arduino Mega2560 is six analog pin (A0-A5), 14 digital pins (D0-D13), ground, Vref, Vin, 3.3V, dan RST (Figure 4).

GPS module is added to the hardware system to get the coordinate spot when executing the measurement. The antenna in the module can be connected to the Arduino system through TTL communication serial. Based on the data sheet, the source of voltage needed is 3-5V with working temperature -40 °C until 85°C. GPS module will be activated at every beginning throughout the track so that the measurement data taken are more valid to be analyzed. GPS module is connected to the Arduino as shown in Figure 5.

Real Time Clock (RTC) in the hardware system has a function to record the time and date of measurement. The module of it is connected to Arduino through 2 cables serial communication like shown in Figure 6. Measurement data will be taken every 1/1000 second in 3 seconds for one time current injection.

The current sensor is placed in the resistivity meter to measure how big the current injected into the soil. The sensor used in this research is ACS758 (Figure 7).
3.3. Designing the Software system

The design of the software system based on the algorithm, includes the organization of the Arduino. That program made by Arduino IDE 1.6.12 application. The current (I) read by sensor ACS758 and the ADC (V) read by A7 analog pin, then the resistance (R) can be calculated. The next step is to define the apparent resistivity $\rho_a$. The value of I, V, and $\rho_a$ are showed in LCD TFT in graphic and saved in SD card with txt format.

3.4. System of Integration

Based on the G57 regulation issued by ASTM, electrodes should be made from light steel with the diameter around 0.475-0.635 and 30-60 cm in length. The material must get heat treatment first to make it hard enough before hitting terrain like dry, land, or gravel. Standard cable for soil resistivity measurement is made from copper material 18-22 AWG. Resistivity meter box is made from plastic as in Figure 8. The top section of the box is made from acrylic and the side part has some holes for well air circulation.

4. Results

The early stage in designing this geoelectricity tool was to test all electronic components. This process is to ensure that all are in good condition. The test is prominent to be done considering the complicated situation that might encounter if the broken component is noticed after it is already installed inside the tool. Because of that reason, to check every component is the very first thing to be done.

Digitalization process was done by combining every device that had been tested. In the beginning, the combining process was done by using cardboard. The purpose is to give a small simulation of the tool that will be made. The next step was taking the data with a small space of electrodes. This process
was done repeatedly until the regression value is close to 1. In this research, we did four times. The data are shown in Figure 9.

The latest data collection and the data is considered decent in the plastic box. The selected plastic box is thick, strong, and waterproof to reduce the potency to be broken when it is being used in the field.

![Figure 9. Tested devices are combined in the box.](image)

After being combined in one plastic box, we have to make sure the tool works properly. The test was done by comparing the value of sensor ACS 712 with a multimeter. Then, the accuracy classified by our standard, under 90% is bad, 90-94% is enough, 95-99% is good, then 100% is excellent. In the beginning, the geoelectric tool was tested by using the multimeter. It showed “good” value. But when it was measured by using sensor ACS 712, the value is quite precise if the current is more than 10 mA. Less than 10 mA, the result is the opposite.

| No. | R1 (ohm) | R2 (ohm) | Multimeter | ACS712 | Accuracy | Classification |
|-----|----------|----------|------------|--------|----------|----------------|
| 1   | 20       | 30       | 333.00     | 360.20 | 92%      | Enough         |
| 2   | 30       | 50       | 241.00     | 234.60 | 97%      | Good           |
| 3   | 50       | 50       | 190.00     | 190.90 | 100%     | Excellent      |
| 4   | 30       | 100      | 200.00     | 212.00 | 94%      | Enough         |
| 5   | 50       | 100      | 125.95     | 142.80 | 87%      | Bad            |
| 6   | 100      | 100      | 89.87      | 98.00  | 91%      | Enough         |
| 7   | 100      | 150      | 77.00      | 82.80  | 92%      | Enough         |
| 8   | 110      | 220      | 65.50      | 68.25  | 96%      | Good           |
| 9   | 220      | 330      | 37.70      | 45.67  | 79%      | Bad            |
| 10  | 420      | 550      | 20.40      | 20.50  | 100%     | Excellent      |
| 11  | 1000     | 2200     | 7.50       | 7.74   | 97%      | Good           |
| 12  | 4700     | 5600     | 2.00       | 3.05   | 48%      | Bad            |
| 13  | 10k      | 22k      | 0.75       | 2.74   | -165%    | Bad            |
| 14  | 33k      | 50k      | 0.26       | 0.81   | -114%    | Bad            |
| 15  | 100k     | 200k     | 0.08       | 7.15   | -8738%   | Bad            |
| 16  | 300k     | 400k     | 0.03       | 5.30   | -1746%   | Bad            |
| 17  | 500k     | 1M       | 0.01       | 5.44   | -54200%  | Bad            |
The repairing process was done by fixing the sensor and program. In the second test, the value of the current result was worse. Meanwhile, the result remains fine if using the multimeter, which means that the circuit is good. But the current reading was worse than the first step. If in the previous, the accuracy is almost 90%, even 100% existed in the last test. A repairing process was executed again, both hardware and software. But the trial result of sensor ACS 712 did not show any changed; even the result is almost the same as the second trial.

Based on those trials, we made some assumption. There was a probability that sensor ACS 712 did not function well. The built circuit was in good condition proven by the precise result when it was measured by a multimeter. To strengthen the assumption, the team did voltage measurement. If the value of the voltage read was precise, then confirmed that the sensor should be replaced.

The test of voltage was done by comparing the voltage read in Arduino and multimeter. After comparing the result, the accuracy is quite good, and the regression value reaches 0.69% and can be categorized as good (Table 1). From this result, the conclusion is the circuit that had been built was in good condition. The voltage and current were also stable like shown in Figure 10. The problem is when it was read by sensor ACS 712.

| No. | R1(ohm) | R2(ohm) | Multimeter | ACS712 | Accuracy | Classification |
|-----|---------|---------|------------|--------|----------|----------------|
| 1   | 20      | 30      | 176.58     | 213.10 | 79%      | Bad            |
| 2   | 30      | 50      | 134.76     | 144.50 | 93%      | Enough         |
| 3   | 50      | 50      | 84.81      | 98.80  | 84%      | Bad            |
| 4   | 30      | 100     | 138.01     | 146.20 | 94%      | Enough         |
| 5   | 50      | 100     | 86.26      | 89.00  | 97%      | Good           |
| 6   | 100     | 100     | 46.37      | 62.00  | 66%      | Bad            |
| 7   | 100     | 150     | 46.84      | 43.80  | 94%      | Enough         |
| 8   | 110     | 220     | 43.61      | 47.66  | 91%      | Bad            |
| 9   | 220     | 330     | 22.32      | 20.40  | 91%      | Bad            |
| 10  | 420     | 550     | 11.60      | 9.86   | 85%      | Bad            |
| 11  | 1000    | 2200    | 5.10       | 5.56   | 91%      | Bad            |
| 12  | 4700    | 5600    | 1.10       | 8.69   | -590%    | Bad            |
| 13  | 10k     | 22k     | 0.52       | 3.31   | -437%    | Bad            |
| 14  | 33k     | 50k     | 0.16       | 5.64   | -3325%   | Bad            |
| 15  | 100k    | 200k    | 0.05       | 10.54  | -20880%  | Bad            |
| 16  | 300k    | 400k    | 0.02       | 7.58   | -37700%  | Bad            |
| 17  | 500k    | 1M      | 0.01       | 5.41   | -53900%  | Bad            |

Figure 10. Regression test between voltage data from Multimeter and Geo-electricity.
5. Summary
The design of the geoelectrical tool had already finished, and all the component has good function. Then, the digitalization process also results in a good performance even in current and voltage. Its proof by good results in the regression process.

References
[1] Lowrie W 2007 Fundamentals of Geophysics (Cambridge University Press: New York)
[2] Reynolds J M 1997 An Introduction to Applied and Environmental Geophysics (Jhon Wiley & Sons Ltd: Chichester)
[3] Roy E 1984 Geotechnical Engineering Investigation Manual (Mcgraw Hill: New York)
[4] Tang CS, Wang D Y, Zhu C, Zhou Q Y, Xu S K and Shi B 2018 Charaterizing drying-induced clayey soil desiccation cracking process using electrical resistivity method Applied Clay Science 1-12
[5] Duomont G, Pilawski T, and Philidias D L 2016 Gravimetric water distribution assessment from geoelectrical methods (ERT and EMI) in municipal solid waste landfill Waste Management
[6] Karanth KR 1987 Groundwater Assessment (Tata McGraw-Hill Book Publishing Co: New Delhi)
[7] Das B M 2002 Principles of Geotechnical Engineering 5th edition (Brooks/Cole: USA)
[8] Telford W M Geldart L P and Sheriff R E Applied Geophysics 2nd edition (Cambridge University)