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DESIGN OF RESISTIVITY METER DATA STORAGE SYSTEM BASED ON ARDUINO MEGA 2560 LABORATORY SCALE MEASUREMENT RESULTS

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ABSTRACT

A resistivity meter can determine the resistivity depth of rock structure, sediment layer, or water surface. So far, the resistivity meter that is frequently employed requires manually recording the measurement results before inputting them into the processing data software, which creates many steps in the geoelectric survey. Therefore, designing a resistivity meter with data storage and low prices is essential. This research aims to design a resistivity meter with a data storage system for measurement results, based on Arduino Mega 2560, for laboratory scale. The sensors used were the INA219 currents sensor and voltage sensor. In addition, the tests were carried out to determine each sensor's accuracy level and test for data storage system of measurement results. This research employed the Schlumberger configuration in the development of the resistivity meter. This research has successfully developed a resistivity meter device with a current sensor accuracy level of 97.28% using the INA219 sensor and a voltage sensor accuracy level of 97.44%. Notably, the accuracy level is high, and the device can perform readings effectively. This research has successfully designed a resistivity meter with data storage for measurement.

Keywords: Geoelectric; Resistivity Meter; Schlumberger; INA219; Data System

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INTRODUCTION

In geophysical studies, one method is used to study the nature of electricity flow under the earth's surface, known as geoelectricity. This method can be used to determine the subsurface layer of the soil. A resistivity meter is a tool that can find resistivity output from below the surface. Detection includes potential, current, and electromagnetic field measurements [1]. The survey was conducted to determine the measurement results of the resistivity value. Estimating resistivity values in the subsurface can be done by flowing current into the ground, measuring the current's strength through the current electrode, and measuring the potential difference through the potential electrode [2].

Resistivity meters can be used to determine the depth of the resistivity of rock structures, sedimentary layers, or the depth of the water table. However, resistivity meters that are often used require manual recording of measurement results before being input into the IP2WIN software, which is one of the many geoelectric data processing applications when processing data, and this makes many steps in geoelectric surveys. This is because having a resistivity meter with a data storage system requires more money; the purchase price of the tool is high, so many resistivity meters in the laboratory or used in the field currently need to be equipped with a data storage system.

Therefore, there is a need for a resistivity tool that can calculate the geometry and resistivity factor values so that field data can be processed directly through the application, saving many steps in conducting geoelectric surveys. So, how is the design of a resistivity meter tool with an Arduino mega 2560-based measurement data storage system, and how is the design of the data storage system equipped with the calculation of geometry and resistivity factor values? This research only tests the accuracy of the INA219 current and voltage sensors. The data generated by the design tool only reaches the calculation of the geometry factor, and the resistivity value is not managed in the geoelectric application. The design tool can only use the Schlumberger method. This research aims to produce a resistivity tool design based on Arduino Mega 2560, equipped with a data storage system based on the measurement results. In addition, this research also includes developing a data storage system design fitted with the calculation of geometry and resistivity factor values for the Schlumberger configuration for further data processing.

The geoelectric method can determine changes in specific resistance in one layer of rock below the ground surface [3]. The working principle of geoelectricity is to measure the resistivity value. The reading of the resistivity value is obtained by passing an electric current into the underground layer through the current electrode. Furthermore, the potential electrode will receive the current by considering the earth as a resistor. The resistivity geoelectric method uses the principle of Ohm's law. The value of the resistance of a material is inversely proportional to the value of the current flowing and directly proportional to the potential difference. The resistance of a material can be influenced by three things: the type of resistance, the length of the resistance, and the area of the resistance itself [4].

The basic concept of the geoelectric method is Ohm's law. Ohm's law states that the potential difference arising at the ends of a medium will be directly proportional to the electric current flowing through the medium. In addition, electrical resistance will also be directly proportional to the length of the medium and inversely proportional to its cross-sectional area. The formula of Ohm's law can be written as follows:

$$V \infty I \; or \; V = I \, . R \qquad (1)$$

According to Ohm's law, resistance (R) is proportional to length (L) and inversely proportional to cross-sectional area (A), as follows:

$$R = \frac{\rho L}{A} \qquad (2)$$

for an electrical circuit, Ohm's law can be written as

$$R = \frac{V}{I} \qquad (3)$$

Based on equations (2) and (3), it can determine the resistivity value used in the geoelectric method [5], namely:

$$\frac{V}{I} = \frac{\rho L}{A}$$

then the resistivity value is obtained in equation (5), which is used in the geoelectric method.

$$\rho = \frac{VA}{IL} \tag{4}$$

Geoelectric methods are closely related to the configuration or arrangement of the geometry of the current and potential electrodes used. For example, a configuration that uses four electrodes in a straight line, with electrodes AB and MN symmetrical to the center point on both sides. These configurations are known as the Wenner and Schlumberger configurations. Each configuration has its particular calculation method for obtaining information about the thickness and resistivity of rocks in the subsurface.

One of the commonly used configurations in geoelectric methods is the Schlumberger configuration. The Schlumberger configuration is used to reveal the characteristics of the rock layer below the ground surface. Each geoelectric measurement configuration has a different K value (geometry factor). If we can measure the potential difference and current flowing through the ground, then the results can be used to calculate the value of rock resistivity based on the change in value against the distance between the electrodes. In the Schlumberger configuration, the electrodes are placed in a straight, symmetrical line to the center point. The distance between current electrodes C_1 and C_2 (AB) is larger than the distance between the two potential electrodes P_1 and P_2 (MN), or the change in MN distance should not be greater than 1/5 of AB distance [6].

By using the Schlumberger configuration, the geometry correction factor can be calculated in equation (5) as follows:

$$K = \frac{\pi}{a}\left[\left(\frac{L}{2}\right)^2 - \left(\frac{a}{2}\right)^2\right] \tag{5}$$

Vertical Electrical Sounding, or what is called (VES) is a resistivity measuring instrument in the vertical direction. The tool is used to determine changes in soil resistivity to depth, and it aims to study variations in rock resistivity below the earth's surface vertically [7]. The depth that can be reached through geoelectric measurements can use geoelectric methods. One method that can be used is the Schlumberger configuration. The Schlumberger configuration is half the total distance (1/2 AB), usually denoted by r. The advantage of the Schlumberger configuration is its ability to detect inhomogeneous rock layers on the surface.

Several resistivity meter geoelectric tool models, such as the NRD 300 Nainura model, were made in Indonesia. The tool can be used for groundwater exploration, geotechnical investigations, environmental studies, geological surveys, mineral prospecting, archeology, and hydrology. On the other hand, a syscall kid resistivity meter, with an RS232 serial made in the United States, is used for automatic SP correction. This includes linear wave correction and stimulation measurements made with voltage and current [8].

Assistance from software is needed to process geoelectric data. One of them is IP2WIN software. This software can analyze geoelectric data using the resistivity geoelectric method with various configurations such as Schlumberger, Wenner, etc. The use of IP2WIN includes several stages. The stages in using IP2WIN software are data input, data error correction, data addition, and cross-section creation [9].

According to the Instrument Society of America, a sensor is a device that can provide input to be used as a response to the magnitude of a particular measurement [10]. In Sinclair, it explains that a sensor is a device that can detect or measure physical quantities [11]. A voltage sensor is required to obtain voltage data from a source or battery. This voltage sensor adopts the voltage divider principle, where two resistors are connected in series, and the reference voltage is obtained from the branching point on the resistor. The resulting voltage will be connected to the Arduino Uno as a microcontroller module to measure and monitor voltage. Based on Ohm's law, which states that the voltage (V) on the resistor is directly proportional to the current (I) flowing through the resistor [12]. The INA219 sensor is one of the sensors that monitor the presence of microcontroller usage power. This sensor can measure load sources up to 26 Vdc and a current of 3.2 A. By multiplying Ohm's law, INA219 can calculate wattage power. The energy measured using this module can reach more than 75 watts of power [13]. The INA219 sensor supports I^2C or SMBUS-COMPATIBLE interfaces, which can monitor shunt and bus voltage with program time conversion and filtering [14].

Data storage can be done by using createWriter( ) for programming in the Arduino microcontroller module and by connecting the Micro SD Card module to the Arduino. The return value of this function needs to be assigned to an object variable of type PrintWriter. Once the file is created, writing to the file is done using the print ( ) method of the variable of type PrintWriter. To end the storage, the flush( ) and close( ) methods of the PrintWriter type variable need to be called, respectively. The flush( ) method is used to ensure all data has been written to the file, while close( ) is used to close the file [15].

METHOD

The research was conducted using an experimental method. Namely, its implementation is carried out in several stages, namely literature study, blog diagram design, and flowchart of the tool working system, resistivity meter design, tool making, current and voltage sensor testing, testing the calculation of the geometry factor (*K*) and *ρ* value by the design tool, and testing the Keypad (data input) and data storage system of the results of a measurement, testing the overall tool. In this research, a literature study was conducted to find relevant data and information about the theoretical basis. The sources used as references in the theoretical basis include books, journals of previous research results, and literature related to the design of this study.

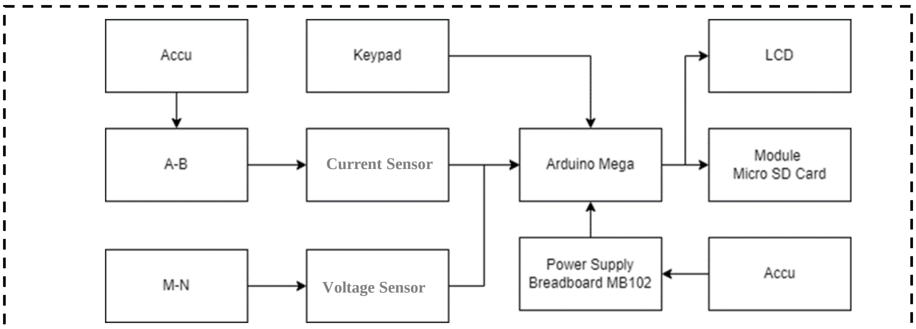

Figure 1. Resistivity Meter Tool Block Diagram

From the block diagram in Figure 1, the overall working principle can be seen; the working principle of this research is that the battery provides power to the MB102 breadboard power supply and then lowers the voltage to 5V to provide power to Arduino mega, as well as the entire tool. For batteries connected to A-B to inject current into the ground. LCD and Micro SD Card modules are used as output, while the current sensor, voltage sensor, and keypad act as data input to the microcontroller module.

The device's design is carried out in several stages based on each function: display, voltage reading function (voltage sensor), current reading function (current sensor), keypad input function, Micro SD Card module data saving and writing function. The following is a schematic of the resistivity meter tool:

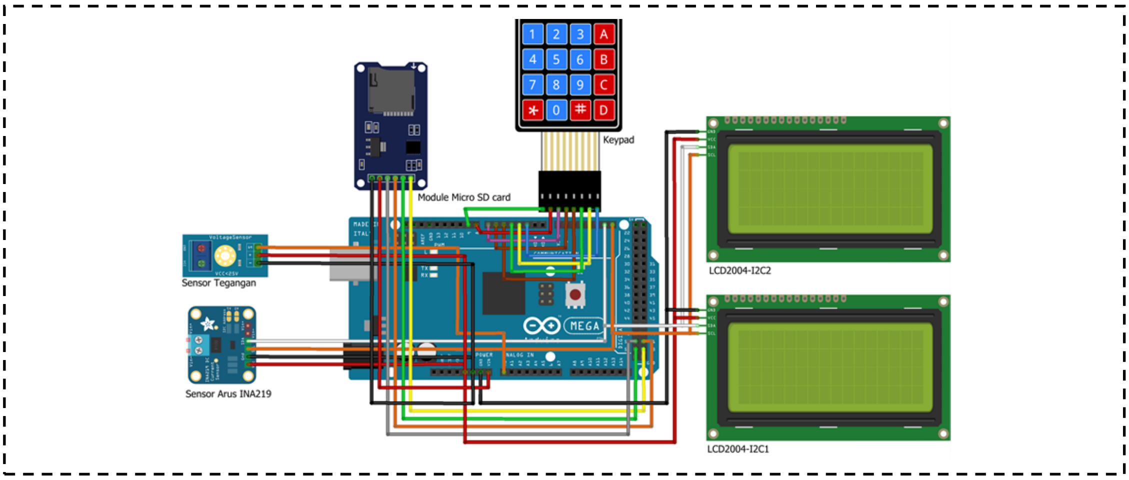

Figure 2. Resistivity meter circuit schematic

The specifications of the tool to be designed are as follows:

- The Arduino Mega 2560 microcontroller module is used as a controller for current and voltage sensors, as well as processing data transfer and receiving data as a whole.
- The current sensor with type INA219 is used to read current values.
- A voltage sensor is used to read voltage values.
- The micro SD card module can write and read data from the microcontroller processes.
- *K*eypad as data input to the microcontroller.
- LCD I^2C 2004 to display the results of readings or calculations by the microcontroller.

The design of the Arduino microcontroller software uses the Arduino IDE software to compile the program code according to the flowchart of the tool work that will be uploaded to the Arduino board. The program code is arranged according to the tool's workflow and the tool system's needs by utilizing existing libraries, such as keypads, dataloggers, I^2C LCDs, and sensors.

They were adjusted from the previously made schematic in Figure 2 so that the tool is designed and arranged according to the schematic, where the voltage sensor utilizes the Analog PIN to send sensor readings. The voltage sensor is connected to Analog Pin A0 so that Arduino can read the analog input provided by the voltage sensor; the current sensor is connected to the SDA SCL PIN, where SDA is Serial data, and SCL is Serial Clock, which is a synchronous serial communication protocol with Arduino. The Micro SD Card module for MISO (Master In Slave Out) is connected to PIN 50, MOSI (Master Out Slave In) is connected to PIN 51, SC*K* is connected to PIN 52, and CS is connected to PIN 52. MISO and MOSI on the Micro SD Card module are data lines for communication. MISO acts as a data receiving line, while MOSI sends data to the microcontroller IC. SC*K* is a synchronization signal where data is only considered valid when SC*K* is high. The Keypad is assembled according to the schematic. Later, the corresponding PIN will be entered into the Program code as the initial variable. The 20x04 LCD utilizes the I^2C serial to be connected to the Arduino, which utilizes SDA SCL as a serial communication.

Testing is carried out simultaneously with the tool making stage. Tests during tool making include testing current and voltage sensors, input functions (Keypad, Micro SD Card module), and output functions (LCD, Micro SD). Furthermore, calculation function testing will be carried out, and the entire tool will be testing resistivity measurements to determine the depth reached by the tool that has been made.

Tests on current sensors and voltage sensors will be carried out with the aim of testing circuit readings. The intended circuit can be seen in Figure 3 as follows, using resistor variations.

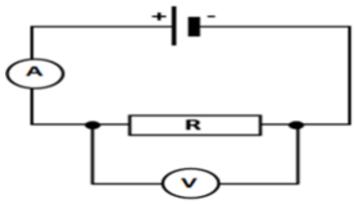

Figure 3. Current Sensor and Voltage Sensor Testing

The current and voltage sensor readings will be compared with the readings from the multimeter to evaluate the sensors' accuracy. The test data, through manual recording and data stored in the device, will be entered into the IP2WIN software. This aims to obtain the K and ρ values and compare the suitability of the K and ρ values produced by the tool with the calculations performed by the IP2WIN software.

The tool evaluation stage is carried out to test an overall tool for each tool function; the evaluation is carried out on soil resistivity measurements with the Schlumberger configuration. The reason for choosing this configuration is the large number of uses of the Schlumberger configuration in taking geoelectric data. Also, this configuration will not require expensive survey costs; the Schlumberger configuration can detect the non-homogeneity of the layers of a rock surface; another reason is that in other configurations, such as Wenner, which requires a relatively large area, it cannot detect homogeneity which affects the calculation results, the dipole-dipole configuration has the disadvantage that the signal strength is minimal for a significant "n" factor value. This evaluation is only done to check each function as a whole and not to compare the measurement results with the results of the actual equipment. The review of the geometry factor value and resistivity value calculation refers to the calculation results of the application value on IP2Win. The reason for using the application is that writing lines of code for the function of writing data to the Micro SD Card is more straightforward and more accessible in implementing the algorithm; this can be seen in the txt file required by the application, compared to other applications which in the initial line in the txt file require information related to what configuration is used and other information. Another reason is that the IP2Win application can be exported to different applications, such as RES2DIV, which is why the application is chosen. The following procedure for the tool evaluation stage will be carried out:

1. Determine each stretch length on the current electrode (AB) and potential electrode (MN).
2. Turn on the resistivity meter tool
3. Insert the memory card
4. Installing the four electrodes
5. All electrodes were combined with the resistivity meter and the cable as a link, and the current was injected.

6. Pressing the AB button and entering the value of the current electrode stretch length (AB)
7. Pressing the MN button and entering the value of the potential electrode length (MN)
8. Pressing the result button to find out the value of the geometry and resistivity factor calculated by the resistivity meter tool
9. Pressing the save button to save the measurement data
10. Pressing the AC button to repeat Steps 1-9 above
11. Repeating Steps 1-9 for the next stretch length.

The data collection techniques used are observation and measurement. Observation is carried out on the test object, and a measurement is taken. To know whether the tool works well or not by the planning of the tool made. The resulting output is current and voltage data and K and ρ value data from the planned tool. Data analysis uses quantitative data analysis with experimental methods. The ability to calculate data accurately is highly dependent on this method.

The flowchart of the working system of this design tool as a whole is the process of inputting AB and MN values, the process of calculating K and ρ values, and also the measurement result data storage system.

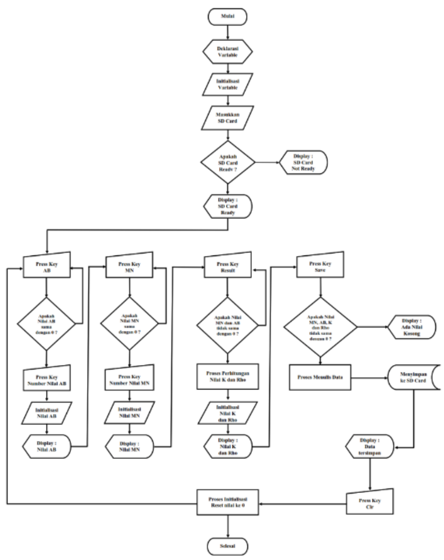

Figure 4. Flowchart Diagram of Tool Design

RESULTS AND DISCUSSION

Testing of the Arduino uno-based resistivity meter design with a data storage system for the measurement results is carried out to determine the function of the tool and sensor for each function through predetermined stages. The results of this research are as follows:

The results of the hardware design (hardware) of the research were as follows:

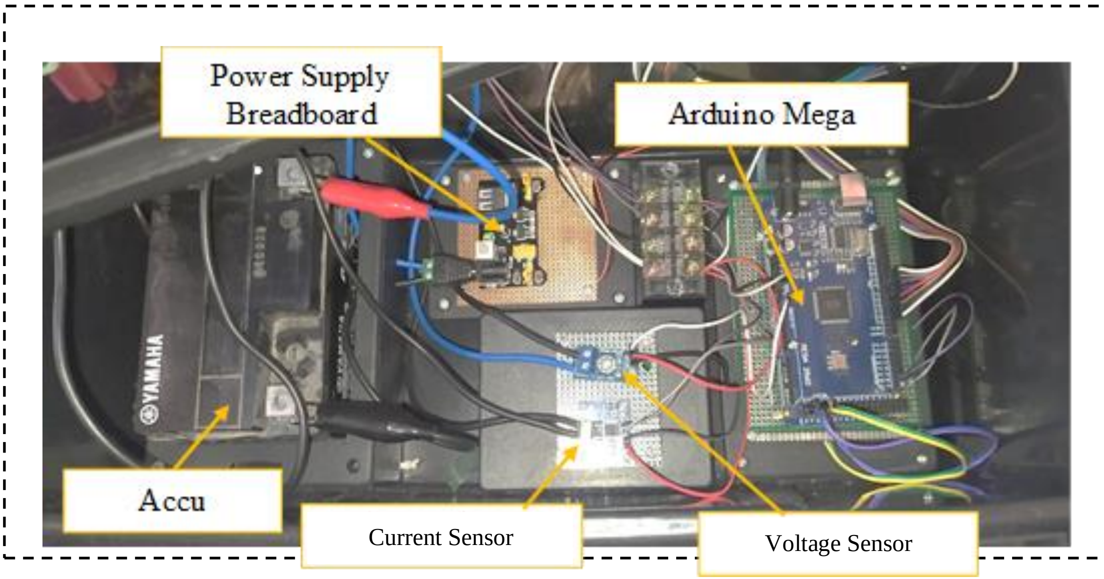

Figure 5. Inside view of the Resistivity Meter Tool

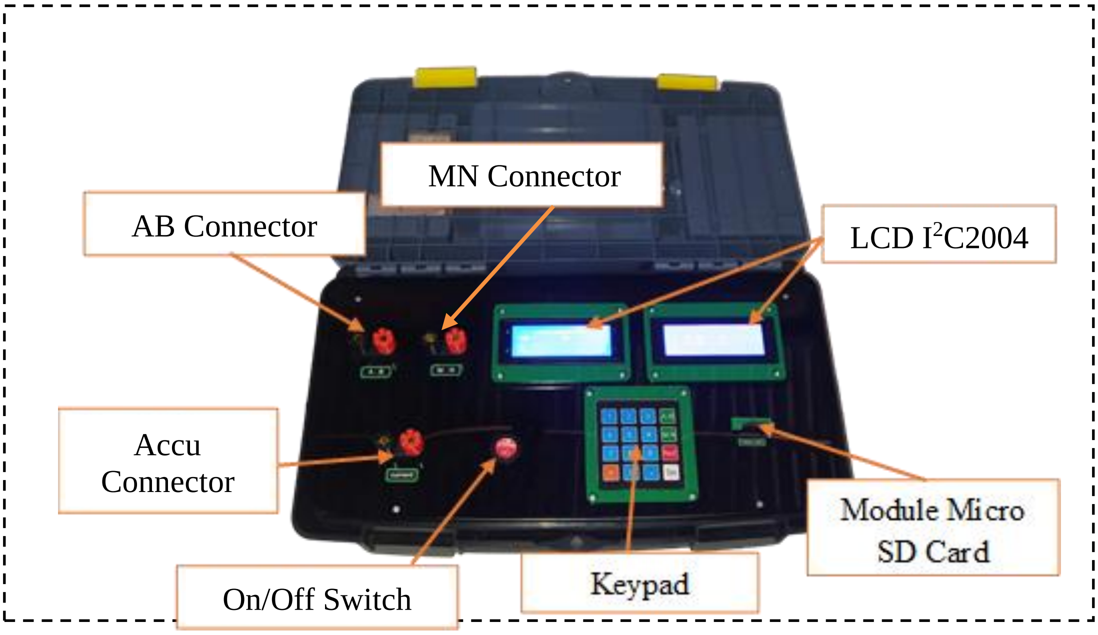

Figure 6. External view of the Resistivity Meter

From Figure 5, it can be seen that the overall picture, where on the inside there are current sensors, voltage sensors, as the central controller or controller, namely Arduino Mega 2560, MB102 breadboard power supply as a step down voltage to 5V for Arduino Mega 2560 power.

In Figure 6, there are 2 LCD I^2C 2004 as output to display the reading or calculation results, a Micro SD Card Module as a place to write/read data, AB and MN connecting ports, and battery connecting ports for injection into the ground, *K*eypad as input to Arduino to input AB and MN values, and other functions.

To determine whether or not the tool is to be used in research, it is necessary to do a test one by one according to its function and testing as a whole. Display function testing was carried out to determine the display function that will be used in the resistivity meter tool, and it can be seen that the display can function correctly. *K*eypad function testing is carried out to determine the keypad response as input and run several commands set in the program code.

Testing the Micro SD Card module: This test is carried out to ensure that the SD card module can read the Micro SD Card and write data into it. After testing, the Micro SD Card Module will function properly. Testing of current and voltage sensors is done with resistors where the readings of the INA219 current sensor and voltage sensor are compared using a multimeter. In this test, a comparison was made between the current readings using a multimeter and the INA219 current sensor and voltage sensor. In this test, the resistance value is sought using the principle of Ohm's law, where resistance has a relationship proportional to the potential difference and inversely proportional to the current. Three kinds of errors can occur in measurements or observations: systematic error, random error, and action error. Systematic error is a type of measurement error that permanently affects a measure's results.

The formula for calculating the error value:

$$\%error = \left|\frac{(Multimeter\ Readings - Sensor\ Readings)}{Multimeter\ Readings}\right| x\ 100\% \tag{6}$$

The results of testing the current sensor and voltage sensor, along with the % error value, can be seen in Table 1. It can be seen that the error reading is below 1% of the difference between the sensor reading and the multimeter reading, which indicates that the tool can be used properly.

Table 1. Testing Data of INA219 Current Sensor and Voltage Sensor

	Multimeter Reading Value			Sensor Reading Value					
Resistors (Ω)	Potential Difference (V)	Current (I)	Resistivity (R)	Potential Difference (V)	Current (I)	Resistivity (R)	%*Error* Potential Difference (%)	%*Error* Current (%)	%*Error* Resistivity (%)
15	2,34	0,1631	14,347	2,29	0,1608	14,241	2,137	1,410	0,737
68	5,51	0,0831	66,306	5,32	0,0805	66,087	3,448	3,129	0,330
82	6,41	0,0845	75,858	6,21	0,0821	75,639	3,120	2,840	0,288
220	8,11	0,0376	215,691	7,91	0,0363	217,906	2,466	3,457	1,027
390	8,23	0,0219	375,799	8,01	0,0212	377,830	2,673	3,196	0,540
470	8,31	0,0181	459,116	8,12	0,0176	461,364	2,286	2,762	0,490
560	8,87	0,0154	575,974	8,72	0,0157	555,414	1,691	1,948	3,570
1000	9,37	0,0095	986,316	9,31	0,0096	969,792	0,640	1,053	1,675
Average error (%)							**2,569**	**2,723**	**1,185**

Table 1 shows the test result data of the INA219 current and voltage sensors by loading on the resistor variation. Based on Table 1, the results of testing the INA219 current sensor and voltage sensor show that the % error of the INA219 current sensor is 2.72% and the voltage sensor is 2.56%. In addition, the resistance value obtained is just a short distance from the tolerance value of the resistor, which is about 5%. So, the current sensor and voltage sensor can function as good readings.

System evaluation is carried out to test the tool as a whole for each function of the tool made; the assessment is carried out on soil resistivity measurements. This evaluation is only done to check each function as a whole and not to compare the measurement results with the actual tool. The assessments carried out are:

1. Evaluation of the output system (LCD and micro SD Card module)
2. Appraisal of the input system (Keypad, INA219 current sensor, and voltage sensor)

It can be seen after the system evaluation that the electrode distance input keypad and command input are appropriate and run well. It is known that the calculation of the two values produced by the resistivity meter and IP2WIN application where the IP2WIN data calculation can be rounded, while the resistivity tool does not do this. This is because the tool program code does not include this function. The function of writing and reading files on the micro SD Card run by the micro SD Card module with Arduino Mega 2560 control runs well when the results of writing to the micro SD Card are by the program code and the purpose of writing data into it, namely the file can be processed using the IP2WIN program.

This tool measures resistivity using the INA219 current sensor and voltage sensor. Also, this tool can calculate the value of K and ρ, where the data will be stored using the Micro SD Card module, and the stored data can be directly processed in the geoelectric data processing application, for example, using the IP2WIN application.

*The K*eypad as an input function can function adequately as data input and commands, as well as several keys such as key save, key results, and critical care, where the key save to save the research data after testing can be used properly. The results key is the key that functions to get the calculation results of the geometry factor (K) and resistivity (ρ) values and the car key is the key to restart from the beginning of the program or delete inappropriate input data.

The Micro SD Card module can read data, namely reading whether the SD Card has a file or not, which later, from the results of the check, can be done to create a new file or write back in the existing file. This flow has been adapted to the workflow of the tool so that it will not create a new file for each data retrieval, so it should be noted that the SD Card used is an empty SD Card or SD Card that has a file with the name txt data after the reading function. The other function is the writing function, which writes data to the Micro SD Card with the writing data specified in the program code. Each piece of written data will be entered into the same file but in a new line to become one data set for data retrieval. Overall, the reading and writing functions on the Micro SD Card module can function appropriately according to the program code that has been written and programmed into the Arduino Mega 2560.

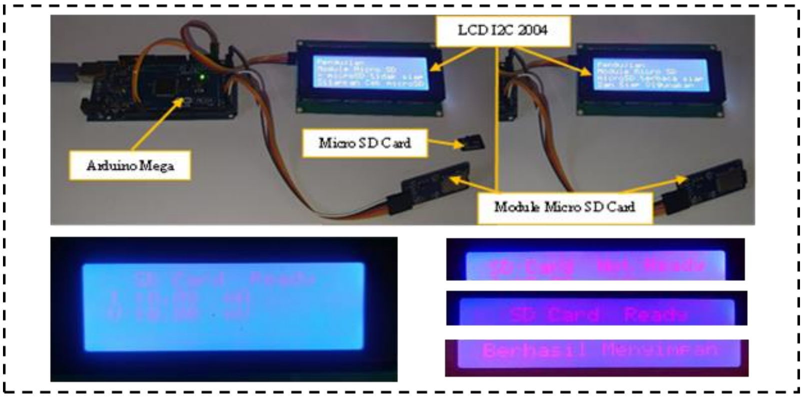

Figure 7. Output System (LCD and Micro SD Card Module

Testing of the micro SD card module is initially conducted separately, as shown in Figure 7 at the top, where it functions properly. Subsequently, in Figure 7 at the bottom, it is seen after testing as a whole according to the tool's workflow and the compatibility of the output function with the code programmed into the Arduino Mega 2560.

Referring to previous research by Muhayadi et al., who conducted tests using resistors with different values [16], in this study, the same thing was done and obtained the results of the % error of the INA219 current sensor of 2.72% and the voltage sensor of 2.56% whose sensor reading accuracy level was 97.28% for the INA219 current sensor and 97.44% for the voltage sensor. This shows that the designed tool is highly conforming to the multimeter reading results.

After testing the display function that displays the output of the program code that has been made, the data storage function, the data input function, and the work system, as well as evaluating the input and output system, it can be seen that this tool can function correctly.

- Current and voltage sensor readings' error rates are 2.72% and 2.56%.
- The tool can calculate the K and ρ values, whose calculations are by the IP2WIN software.
- The tool can read files on the SD card and write selected data (when taking data) into a micro SD card with selected data, ready to be used in data processing.
- Stored data can be directly used for geoelectric data processing or through excel.

The drawback of this tool is that there is no increase in the value of the injection current. The specifications of the tools are as follows:

Table 2. Specifications of the Designed Equipment

Specifications	Description
Power supply	12 volt
Output Voltage	12 Volt
Max Current Sensor Reading	± 3,2 A
Max Voltage Sensor Reading	25 V
System Readout	Digital
Data Storage	True

CONCLUSION

Based on the results of research and discussion, it can be concluded that a resistivity meter design has been successfully made with an Arduino Mega 2560-based measurement data storage system, which is composed of several functions such as current reading and voltage reading functions, input functions, output functions (display and data recording). The error rate of the current sensor reading is 2.72%, and the voltage sensor is 2.56%. The tool can calculate the value of K and ρ; the tool can write and read data into a micro SD card with selected data ready to be used in data processing. Stored data can be directly used for geoelectric data processing or through excel. The disadvantages of this tool are that it can only use the Schlumberger configuration, and there is no increase in the value of the injection current. A system for storing measurement data using a micro SD card module has been successfully created with the calculation of K and ρ values, and the storage file can be processed directly in the geoelectric data processing application, which is used for data processing in the IP2WIN application. The design researchers have made some shortcomings that need to be improved, both in terms of software and hardware. To overcome this, researchers recommend further development focusing on three main aspects. First, increasing the injection current value is necessary to get more accurate and representative results. Second, it is required to round the measurement data values to avoid uncertainty and errors in the analysis. Finally, carrying out tests using previously measured soil or rock values is essential. By improving these areas, the design can be closer to the desired level of perfection.

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