Jurnal Penelitian Fisika dan Aplikasinya (JPFA)
Volume 15, Issue 2, 56-68 2025
https://journal.unesa.ac.id/index.php/jpfa/
p-ISSN: 2087-9946
e-ISSN: 2477-1775

Development of an ESP32-Based Resistivity Meter with Integration of ACS712 Current Sensor, ADS1115 Voltage Sensor and Neo6MV2 GPS Module

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Received: 6 December 2025; Revised: 19 December 2025; Accepted: 30 December 2025

Abstract

This study aims to develop an ESP32-based resistivity meter instrument integrated with an ACS712 current sensor, an ADS1115 voltage sensor, and a Neo6MV2 GPS model. This IoT-based instrument can be operated remotely so that it can streamline measurements. The method used in this study is the R&D method where this method aims to create innovations in the form of new and applicable products, systems, or models, and test their effectiveness. The research stages start from hardware design assembled based on block diagrams, software design using the Arduino IDE using the C++ programming language, testing and data collection. The results of the study showed that the ADS 1115 sensor has an average measurement error (% error) of 5.1%, the ACS 712 current sensor has an average% error of 3.6%, and the Neo6MV2 GPS module has an average latitude difference of 0.000016 degrees (1.81 m) and longitude of 0.000025 degrees (2.83 m). Measurements can be performed remotely via smartphone using the ESP32 at a distance of 41 m. Comparison of the measurement data from the IoT resistivity meter with a standard resistivity instrument were obtained in the range of 7.771% - 12.815% with an average error of 9.625%. Based on these measurement results, the resistivity values this indicates that this instrument can be used to identify mined minerals and groundwater aquifers.

Keywords: *IoT integration, ESP32 based system*

How to cite: Nurfalaq A, Manrulu RH, and Ramli I. Development of an ESP32-Based Resistivity Meter with Integration of ACS712 Current Sensor, ADS1115 Voltage Sensor and Neo6MV2 GPS Module. *Jurnal Penelitian Fisika dan Aplikasinya (JPFA)*. 2025; 15(2): 56-68. DOI: https://doi.org/10.26740/jpfa.v15n2.p56-68.

INTRODUCTION

The geoelectric method is a geophysical method used to identify subsurface layers. The instrument used is called a resistivity meter. In principle, the geoelectric method utilizes an electric current injected into the ground through a pair of electrodes, then measures the resulting potential difference. By knowing the current flowing and the resulting potential difference, the resistivity of the rock can be determined [1].

Resistivity meters have been widely used in geoelectric surveys to identify subsurface conditions, such as the presence of minerals, bedrock, and groundwater aquifers. Currently, resistivity meters that are inexpensive, accurate, easy to use, and can be operated remotely are still limited. Commercial instruments are generally expensive, while previously developed instruments still have limitations in sensor accuracy, measurement stability, location data integration, and IoT features. Therefore, this study developed an ESP32-based resistivity meter that integrates an ACS712 current sensor, an ADS1115 voltage sensor, and a Neo6MV2 GPS to produce a more practical, documented, and suitable resistivity measuring instrument for the identification of mining minerals and groundwater aquifers.

The development of this resistivity meter began with the design of a geoelectric tool as a subsurface detector that uses a current inverting circuit and a power supply in the form of a battery whose number can be modified so that the input voltage and output voltage can be adjusted to the needs in the field [2]. The designed tool was tested with field measurements and the results were compared with the standard resistivity meter IPMGeo4100 [3]. Furthermore, the designed tool was implemented in measuring landslide slip planes [4] and identifying the depth of groundwater aquifers [5]. Microcontroller technology can be applied to the development of Arduino Uno-based resistivity tools. Previously, this microcontroller has been used in the automation of plant watering tools [6], soil moisture detection [7] and the Internet of Things (IoT) for Smart Home design [8]. The microcontroller used is an Arduino Mega2560, supported by current sensors, voltage sensors, an inverter, a relay, an LCD, and an SD card module for storing measurement results. This tool performs well with a measurement error of 13.95% [9].

The resistivity tool using the Arduino Uno R3 microcontroller with the nRF24L01+ transceiver has an average error of 9.53% for sand testing, 18.80% for humus soil testing, 14.10% for clay testing, and 29.40% for field testing [10]. The development of an Arduino-based resistivity meter has also not yet produced accurate measurement results [11]. This research aims to design and build an Internet of Things (IoT)-based Smart Georesistivity prototype that can be operated remotely to streamline field measurements.

METHOD

This research uses the Research and Development (R&D) method, referring to Sugiyono's model. These stages include potential and problems, data collection, product design, design validation, design revision, product trials, product revisions, and usage trials [12], as shown in the figure 1.

Potential and Problem

The first step was to identify the potential and challenges in using resistivity meter instruments. The potential identified was the need for geoelectrical instruments that could be used for surveys, learning, and research. However, challenges include the relatively high price of resistivity meters, limited digital features, and suboptimal remote operation. Therefore, the development of a more practical, economical, and IoT-enabled ESP32-based resistivity meter instrument is necessary.

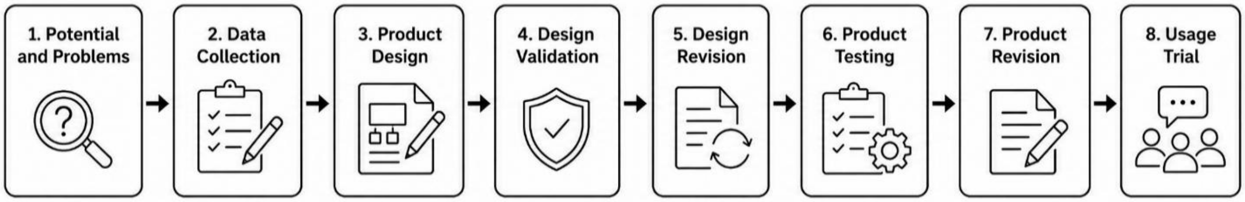


Figure 1. Stages of the R&D method based on the Sugiyono model

Data Collection

The data collection phase involved literature review and a review of previous research on geoelectrical instruments, microcontroller-based resistivity meters, current sensors, voltage sensors, GPS modules, and IoT technology. This initial data was used to determine component requirements, system design, and the operating principles of the instruments to be developed.

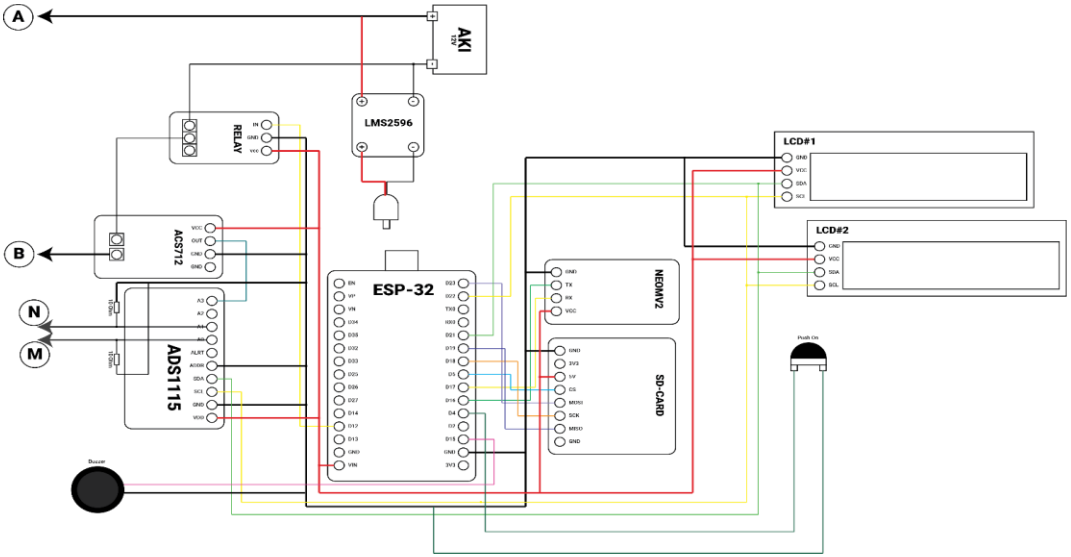


Figure 2. Block diagram of the resistivity meter

Product Design

At this stage, the product design is carried out in the form of an ESP32-based resistivity meter instrument. The product design includes hardware and software design. The hardware consists of ESP32 as the main microcontroller, ACS712 current sensor, ADS1115 voltage sensor, Neo6MV2 GPS module, LCD, Micro SD Card, 12 volt battery voltage source, and supporting circuits. Meanwhile, the software is designed using the Arduino IDE with the C++ programming language to manage sensor readings, data storage, data display, and remote connections via smartphone or laptop (Figure 2).

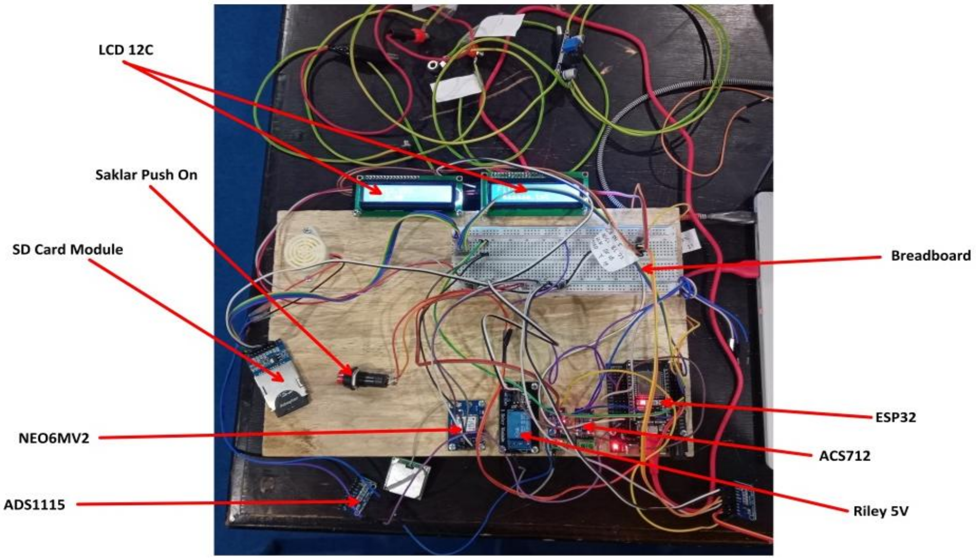


Figure 3. Resistivity meter circuit

The working algorithm starts from the initialization of the ACS712, ADS1115, GPS Neo6MV2, LCD, Micro SD Card, and Wi-Fi sensors, then the system reads raw data in the form of current from the ACS712 sensor and voltage from the ADS1115. The results of the data reading in the form of current, voltage, and GPS coordinates are then displayed on the LCD, saved to the Micro SD Card, and sent to the local web interface so that users can monitor the measurement results directly. Then the apparent resistivity value is calculated using equation (3).

Design Validation

Design validation is performed to ensure that the instrument design meets development objectives. Validation is performed by checking the suitability of the block diagram, hardware circuit, software workflow, and the function of each component. At this stage, the instrument design is evaluated to ensure the current sensor, voltage sensor, GPS module, data storage system, and ESP32 connection can work together (Figure 3).

Design Revision

After the design is validated, improvements are made to any deficient components. Revisions can be made to the circuit layout, component selection, sensor connection paths, program flow, data display, and wireless communication system. This stage aims to make the instrument more stable, easier to use, and ready for testing.

Product Testing

Testing the ADS1115 and ACS712 sensors is performed by comparing the sensor readings with a standard multimeter. The ADS1115 sensor is connected to a power supply with several voltage variations. The ACS712 sensor is connected to a 101.5-ohm load and a power supply with several voltage variations so that the current flowing in the circuit follows Ohm's Law. The sensor readings are then compared with the measurements from a standard multimeter. The measurement error is calculated using the equation:

$$\%error = \left|\frac{Standart\ Instrumen\ Reading - Sensor\ Reading}{Standart\ Instrumen\ Reading}\right| \times 100\% \tag{1}$$

The Neo6MV2 module was tested by comparing the coordinate readings of the Neo6MV2 module with those of a Garmin 73 GPS. Ten points were randomly selected. The Neo6MV2 module measurement error was calculated using the equation:

$$\%error = \left|\frac{GPS\ Coordinate - Sensor\ Coordinate}{GPS\ Coordinate}\right| \times 100\% \tag{2}$$

The ESP32 signal was tested by measuring the transmitted signal strength at various distances. The ESP-32 Wi-Fi range was measured using the Wi-Fi Signal Meter Pro application.

Product Revision

Based on the results of initial testing, product revisions were conducted to address identified weaknesses. These revisions included adjusting the sensor reading program, calibrating current and voltage values, improving component connections, and refining the display and data storage systems. This step was carried out to ensure the instrument's readings were more stable reliable.

Usage Trial

The usage trial was conducted through laboratory testing using a 1.2 x 0.5 x 0.5 meter test tank. The test tank was conditioned in three conditions: sand and gravel, sand and gravel with rock chunks, and sand and gravel with water. Measurements were conducted using Wenner, Wenner-Schlumberger, and Dipole-dipole configurations. This stage aims to determine the instrument's ability to read resistivity values under different material conditions. Tests in the test tank were performed under various conditions. In the first condition, the test tank was filled with 0.3 m of gravel (Figure 4a). In the second condition, rock chunks were added to the test tank to condition the presence of mineral-bearing igneous rock or bedrock (Figure 4b). In the third condition, the test tank containing sand was filled with water, creating two layers: a water-saturated layer and an unsaturated layer of sand (Figure 4c).

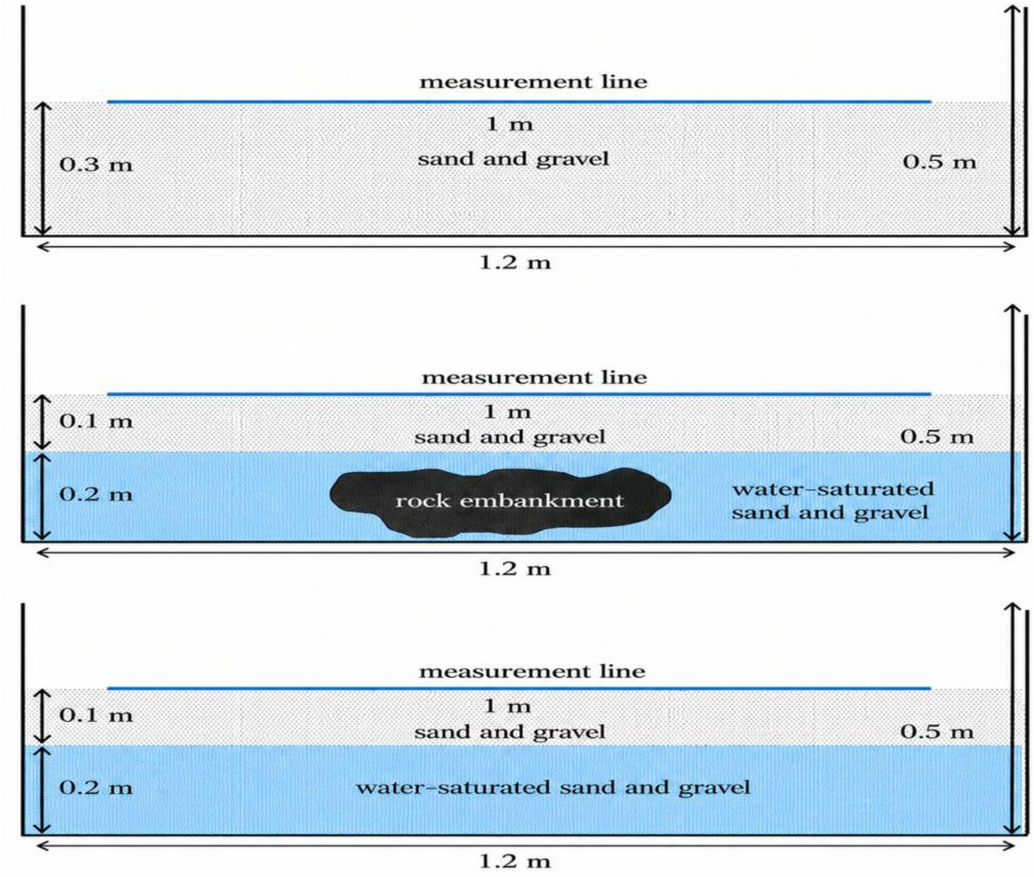


Figure 4. Cross-sectional model of laboratory testing. (a) Condition I (top), (b) Condition II (middle) and (c) Condition III (bottom)

In each of these conditions, measurements were made with a span length of 1 m and an electrode spacing of 0.1 m (a). For each condition, three measurements were performed using three different electrode configurations: Wenner, Wenner-Schlumberger, and dipole-dipole. The results of each measurement were then compared with the material layer model in the test tank. To calculate the resistivity value, use the equation:

$$\rho_a = K\,\frac{\Delta V}{I} \tag{3}$$

Where K is the geometry factor, the value of which depends on the configuration used.
The geometry factor equation for each configuration can be seen in the following table.

Table 1. Geometry factors of several configurations

No	Configuration	Equation
1	Wenner	$K = 2\pi a$ (4)
2	Wenner-Schlumberger	$K=\pi\, n\, (n+1)\, a$ (5)
3	Dipole dipole	$K = \pi\, n\, (n+1)(n+2)\, a$ (6)

RESULTS AND DISCUSSION

ADS1115 Sensor Testing

The voltage sensor test aims to determine the stability of the voltage reading against the applied current. The test was conducted twice (Table 2).

Table 2. ADS1115 sensor test results

Voltage (Volt)	Measured Voltage (Volt)				Error (%)	
	Sensor		Multimeter			
	Testing I	Testing II	Testing I	Testing II	Testing I	Testing II
12	12.77	12.77	12.26	12.26	4.2	4.2
9	9.35	9.4	9.18	9	1.9	4.4
6	5.77	5.8	5.92	5.9	2.5	1.7
3	2.64	2.7	3.09	3	14.6	10.0
Average error					5.8	5.1

The table above shows the results of the sensor testing. In experiment I, the average error percentage was 5.8%, while in experiment II, the average error percentage was 5.1%. This indicates that the ADS1115 voltage sensor readings are quite accurate and stable.

ACS712 Current Sensor Testing

The purpose of testing the current sensor was to determine the sensor's response to the applied current. The current sensor was connected to a 3 Volt, 6 Volt, 9 Volt, and 12 Volt DC voltage source and a 101.5 Ohm resistor. The current flowing in the circuit was measured at various potential difference levels. The measurement results using the ACS712 sensor were then compared with those measured using a multimeter. The ACS712 sensor test results are shown in the following table.

Table 3. ACS712 Sensor Test Results Resistor : 101.5 Ohm

Voltage (Volt)	Rated Current (A)		Error (%)
	Multimeter	ACS712	
3.07	0.01	0.0249	1.5
5.87	0.07	0.0181	5.2
9.18	0.02	0.0603	4.4
12.33	0.25	0.2829	3.3
Average			3.6

The table above shows the results of the ACS712 sensor test. The test results indicate that there is no significant difference between the current measurements using a multimeter and the ACS712 sensor. The average current reading difference is 0.04 A, with an error of 3.6%. This indicates that the ACS712 current sensor readings are quite accurate and stable.

Neo6MV2 GPS Module Testing

The core of this module is the NEO-6M GPS chip from u-blox. This chip is small but packs a wealth of features into its compact frame. This module can track up to 22 satellites on 50 channels and achieves a peak sensitivity of -161 dB, while using only 45 mA of supply current [13]. GPS Neo 6MV2 has quite good specifications for location tracking based on testing with an average coordinate data reading speed of 0.2 meters/second. Based on the accuracy test of GPS Neo 6MV2 against smartphone GPS, the coordinate point reading by GPS Neo 6MV2 is quite good because it has a latitude difference of 0.00012 and longitude of 0.00020 when compared to smartphone GPS [14].

The Neo6MV2 GPS module was tested by comparing coordinate measurements with a Garmin 73 GPS. Coordinates were taken at 10 points in the UNCP Campus II area in Palopo, under various terrain conditions, such as open areas, under trees, and between buildings. The results of coordinates taken using the Garmin 73 GPS and the Neo6MV2 GPS module are shown in Table 4.

Table 4 shows the coordinate readings from the Garmin 73 GPS and the Neo6MV2 GPS module. The smallest difference in latitude readings was 0.000003 degrees in an open area near water, and the largest was 0.000049 degrees near a building. The average difference in latitude readings was 0.000016 degrees. For longitude coordinates, the smallest reading was 0.000005 degrees between two buildings, and the largest reading was 0.000098 degrees under a tree. The average difference in longitude coordinate readings is 0.000025 degrees.

Table 4. Results of taking coordinates from the Garmin 73 GPS and Neo6MV2 GPS Module

No	**GPS Garmin 73**		**GPS Neo6mv2 Module**		**Difference**	
	Lattitude	**Longitude**	**Lattitude**	**Longitude**	**Lattitude**	**Longitude**
1	-2.987740	120.188130	-2.987748	120.188228	0.000008	0.000098
2	-2.987990	120.188610	-2.987962	120.188641	0.000028	0.000031
3	-2.988500	120.188470	-2.988496	120.188491	0.000004	0.000021
4	-2.988560	120.188740	-2.988567	120.188776	0.000007	0.000036
5	-2.987950	120.188800	-2.987933	120.188795	0.000017	0.000005
6	-2.988130	120.189040	-2.988179	120.189055	0.000049	0.000015
7	-2.987920	120.189490	-2.987897	120.189498	0.000023	0.000008
8	-2.987620	120.188850	-2.987623	120.188857	0.000003	0.000007
9	-2.987450	120.188530	-2.987445	120.188554	0.000005	0.000024
10	-2.987220	120.188690	-2.987238	120.188700	0.000018	0.000010

Overall, the coordinate readings from the Neo6MV2 GPS module are very good. Based on accuracy testing of the Neo 6MV2 GPS against a Garmin 73 GPS, the Neo 6MV2 GPS readings on the resistivity meter have an average difference in latitude of 0.000016 degrees (1.81 m) and longitude of 0.000025 degrees (2.83 m) compared to the Garmin 73 GPS. The Neo6MV2 GPS module embedded in the resistivity meter can be used as a coordinate recorder for measurement points in lieu of a survey GPS.

ESP-32 Microcontroller Testing

In this prototype, the ESP-32 serves as the main microcontroller, running the resistivity meter system, reading and displaying data from sensors and modules, and transmitting data wirelessly via Wi-Fi, which is integrated into the ESP-32 system itself. Users can remotely retrieve data through a smartphone app. The ESP-32 Wi-Fi range was measured using the Wi-Fi Signal Meter Pro app. Test results showed that the maximum range reached by the resistivity meter Wi-Fi instrument in open fields, trees, and buildings was 41-44 m.

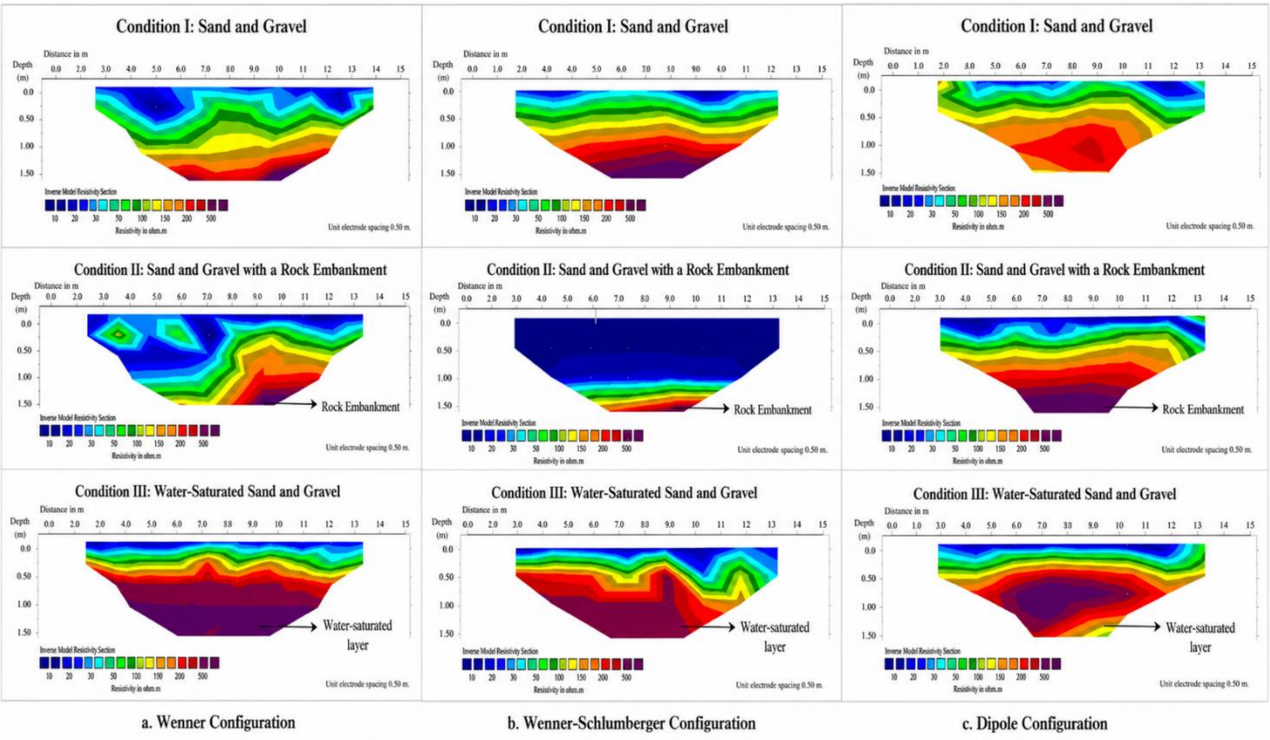
Laboratory Testing

Testing of the resistivity meter in the laboratory was carried out in a glass tub measuring 1.2 x 0.5 x 0.5 m whose contents had been conditioned. In condition I, the glass tub was filled with gravel sand with a thickness of 0.3 m. In condition II, the glass tub was filled with gravel sand and rock chunks. The rock chunks used were iron ore containing iron minerals such as magnetite, as many as 3 pieces with dimensions of 30 x 16 cm each. The rock chunks were planted into the sand at a depth of 0.14 m in a transverse position. The use of this iron ore was intended to test the ability of the resistivity meter to identify mining minerals. Meanwhile, in condition III, the glass tub was filled with gravel sand with a height of 0.3 m and then filled with water with a height of 0.2 m to create conditions of water-saturated and water-unsaturated soil layers. This was intended to see the ability of this resistivitimeter to identify the presence of groundwater aquifers. In these three conditions, geoelectric measurements were carried out using the Wenner, Wenner-Schlumberger and dipole dipole configurations.

Measurements using the Wenner configuration were carried out on a path length of 1.2 m with a distance between electrodes of 0.1 m. The measurement results in condition I (sand gravel) obtained a resistivity value range of 0.503–3390 Ohm.m. In condition II (sand gravel + rock boulders), a resistivity range of 0.497–24259 Ohm.m was obtained. At a depth of 0.14 m where the rock boulders are located, the resistivity value is 1110–24259 Ohm.m. While in condition III (sand gravel + water) the resistivity value range is 1.44–80.2 Ohm.m. The water-saturated layer at a depth of 0.1 m has a resistivity of 25.4–80.2 Ohm.m. Based on these measurement results, the resistivity values obtained from these three conditions are in accordance with the reference resistivity values of the material used. This shows that this resistivity meter can be used to identify mining minerals and groundwater aquifers (Figure 5a).

Measurements using the Wenner-Schlumberger configuration were carried out on a path length of 1 m with an inter-electrode distance of 0.1 m. The measurement results in condition I (sand gravel) obtained a resistivity value range of 0.573–4888 Ohm.m. In condition II (sand gravel + rock boulders), a resistivity range of 224–6478 Ohm.m was obtained. At a depth of 0.14 m where the rock boulders are located, the resistivity value is 2011–6478 Ohm.m. While in condition III (sand gravel + water) the resistivity value range is 2.57–40.5 Ohm.m. The water-saturated layer at a depth of 0.1 m has a resistivity of 27.3–40.5 Ohm.m. Based on these measurement results, the resistivity values obtained from these three conditions are in accordance with the reference resistivity values of the material used. This shows that this prototype can be used to identify mining minerals and groundwater aquifers (Figure 5b).

Measurements using the dipole dipole configuration were carried out on a path length of 1 m with a distance between electrodes of 0.1 m. The measurement results in condition I (sand gravel) obtained a resistivity value range of 4.07 – 1180 Ohm.m. In condition II (sand gravel + rock boulders), a resistivity range of 7.05 – 308867 Ohm.m was obtained. At a depth of 0.14 m where the rock boulders are located, the resistivity value is 14576–308867 Ohm.m. While in condition III (sand gravel + water) the resistivity value range is 7.63–889 Ohm.m. The water-saturated layer at a depth of 0.1 m has a resistivity of 228–889 Ohm.m (Figure 5c).



a. Wenner Configuration b. Wenner-Schlumberger Configuration c. Dipole Configuration

Figure 5. Resistivity cross-section

Field testing of this IoT-based resistivity meter used a Schlumberger configuration with a 50-m span at the UNCP Faculty of Agriculture Experimental Garden. The measurement results were then compared with a standard IPMGEO 4100 resistivity meter, as shown in the following Table 5.

Tabel 5. Field test results of IoT resistivity meter with standard resistivity meter

AB/2	**MN/2**	**Resistivity (Ohm.m)**		Error (%)
		Resistivity meter IoT	**Resistivity meter Standar (type IPMGEO 4100)**	
1,5	0.5	3.591	3.255	10.309
3	0.5	1.160	1.272	8.798
4	0.5	4.726	4.296	10.002
5	2	1.838	2.013	8.718
6	2	2.905	3.264	11.006
8	2	7.612	8.731	12.815
10	2	13.457	15.107	10.921
15	2.5	14.970	16.286	8.077
20	2.5	32.114	29.781	7.834
25	2.5	23.971	22.242	7.771
Average				9.625

Table 5 shows a comparison of the measurement data from the IoT resistivity meter with a standard resistivity instrument. The test results were obtained in the range of 7.771% - 12.815% with an average error of 9.625%. This shows that the resistivity meter reading still has a difference with the resistivity meter. This difference is influenced by sensor sensitivity, ADC resolution, current stability, circuit quality, electrode contact, and calibration process. This is in line with research showing that sensor and microcontroller-based measurement systems still require calibration to improve reading accuracy [15]. Thus, the tool developed can be used as an initial prototype, but still needs improvement so that the measurement results are more stable and closer to standard values.

The test results of the ADS1115, ACS712, and Neo6MV2 GPS modules show that the main components of the ESP32-based resistivity meter instrument have been able to work quite well and support the resistivity measurement function. The ADS1115 voltage sensor produces an average measurement error of 5.1%, which indicates that the voltage reading is relatively stable and close to the standard multimeter value. The ACS712 current sensor obtains an average error of 3.6%, so it can be said to be quite good at reading the electric current flowing in the measurement circuit. Meanwhile, the Neo6MV2 GPS module is able to read coordinate positions with an average difference in latitude of 0.000016 degrees or about 1.81 m and longitude of 0.000025 degrees or about 2.83 m compared to the Garmin GPS 73. These results indicate that the sensor system and modules used have met the basic needs of the instrument, namely reading voltage, current, and measurement position in an integrated manner.

The results of resistivity measurements in a glass tub indicate that variations in resistivity values in the Wenner, Wenner-Schlumberger, and dipole-dipole configurations are influenced by the physical conditions of the material, especially porosity, water saturation, and electrical conductivity. In gravel sand, resistivity tends to be higher because the pores are not yet evenly filled with water so that the electrical current conduction path has not been formed properly. In gravel sand with rock chunks, resistivity values increase more clearly because the rock is more compact, has lower porosity, and limited water content so that electric current is more difficult to flow. Conversely, in gravel sand with added water, resistivity decreases because water fills the pore space and increases the electrical conductivity of the material. The differences in response of the three configurations indicate that Wenner provides relatively stable results, Wenner-Schlumberger is able to distinguish vertical and lateral layer changes, while dipole-dipole is more sensitive to sharp resistivity contrasts. Thus, the test results show that the developed resistivity meter instrument is able to record subsurface changes influenced by porosity, water saturation, and electrical conductivity. Based on these measurement results, the resistivity values this indicates that this instrument can be used to identify mined minerals and groundwater aquifers.

This resistivity meter is designed to be more efficient through the use of low-power components, such as the ESP32, ACS712 sensor, ADS1115, and Neo6MV2 GPS, as well as a portable 12-volt battery power source. The ESP32 also has a power saving feature, so energy can be saved when the tool is not actively taking readings. The main power consumption comes from current injection, Wi-Fi, GPS, LCD, and data storage. Therefore, data readings and storage are carried out periodically to make the tool more energy efficient and suitable for use in geoelectric surveys in the field.

The limitations of field application of resistivity meters are influenced by unstable environmental conditions. Environmental noise, such as from power lines, vehicles, or surrounding activity, can make current and voltage readings less stable. Electrode contact resistance can also change due to differences in humidity, soil density, and electrode installation quality, so that the current entering the soil is not always optimal. Furthermore, terrain variability such as topography, rocks, plant roots, standing water, and heterogeneous soil layers can cause resistivity results to be more complex. Therefore, field measurements require calibration, proper electrode installation, and data repetition to ensure more accurate results.

CONCLUSION

Based on the results and discussion above, it can be concluded that this resistivity meter consists of an ADS1115 sensor with an average measurement error (% error) of 5.1%, an ACS 712 current sensor with an average error of 3.6%, and a Neo6MV2 GPS module with an average latitude difference of 0.000016 degrees (1.81 m) and a longitude of 0.000025 degrees (2.83 m). Measurements can be made remotely via a smartphone using ESP32 at a distance of 41 m. Comparison of the measurement data from the IoT resistivity meter with a standard resistivity instrument were obtained in the range of 7.771% - 12.815% with an average error of 9.625%. Based on these measurement results, the resistivity values this indicates that this instrument can be used to identify mined minerals and groundwater aquifers.

ACKNOWLEDGMENT (OPTIONAL)

We would like to express our gratitude to the Directorate of Downstreaming and Partnerships, Directorate General of Research and Development, Ministry of Higher Education, Science and Technology through the 2025 Research Downstreaming Program – Model and Prototype Testing grant.

AUTHOR CONTRIBUTIONS

The Authors must state all of the Author's contributions to this research/manuscript. The contribution must be stated in the term of CRediT (Contributor Roles Taxonomy), see Appendix 1. **Example**: Budi Jatmiko: Conceptualization, Methodology, and Validation; Utama Alan Deta: Methodology, Formal Analysis, Resources, and Writing - Original Draft; and Nurita Apridiana Lestari: Data Curation, Project Administration, and Writing - Original Draft.

DECLARATION OF COMPETING INTEREST

The authors declare no known financial conflicts of interest or personal relationships that could have influenced the work reported in this manuscript.

DECLARATION OF ETHICS

The authors declare that the research and writing of this manuscript adhere to ethical standards of research and publication, in accordance with scientific principles, and are free from plagiarism.

DECLARATION OF ASSISTIVE TECHNOLOGIES IN THE WRITING PROCCESS

The authors affirm that Generative Artificial Intelligence and other assistive technologies were not excessively utilized in the research and writing processes of this manuscript.

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