

## Design of a smart automated switching multi-channel, multi configurations resistivity meter

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**Abstract** – The resistivity method uses a resistivity meter to measure subsurface resistivity by measuring voltage and current. Conventional data acquisition involves manual electrode movement, which is time-consuming and error-prone. This research developed a multi-channel smart resistivity meter based on Internet of Things (IoT) technology with automatic electrode switching and automated measurements for Schlumberger, Wenner, and Dipole-dipole configurations. The automatic switching system uses relays controlled by an ESP32 master controller. The measurement system employs shunt resistor-based current sensors and voltage divider-based voltage sensors, integrated with Arduino Uno microcontrollers and ESP32 master. Data is automatically stored in cloud storage and controlled via mobile application. Testing results show 3% voltage and 2% current reading errors, with 92% voltage and 96% current precision within 0-100V and 0-100mA ranges. The system successfully performs automatic switching and uploads real-time data every 5 seconds, significantly improving geoelectrical data acquisition efficiency.

**Keywords:** Smart resistivity meter, IoT, electrode switching, cloud storage, geoelectric.

### INTRODUCTION

The geoelectric observation method in geophysics utilizes instruments such as resistivity meters to measure the resistivity value of an area. The resistivity data is then processed through inversion to produce one- to three-dimensional cross-sections of the surveyed subsurface area. The results of the inversion in the form of these models can be utilized for various geophysical exploration purposes [1].

Resistivity meters generally work using four main electrodes with different functions. Two electrodes function to form a current path at a certain distance, while the other two electrodes act as electrical potential meters. The data acquisition process is carried out by moving the electrodes according to the configuration used for each measurement. The operator records the data obtained manually from the beginning to the end of the survey. Commonly used electrode configurations include Schlumberger, Wenner, *Dipole-dipole*, or a combination of several of these configurations [2].

Several studies have been conducted to improve the efficiency of the geoelectric data acquisition process, such as integrating a resistivity meter with an Arduino MEGA microcontroller and a simple GUI, and

designing a multi-channel resistivity meter with 16 electrodes specifically for Schlumberger configuration [3][4]. With the development of technologies such as the Internet of Things (IoT) and cloud computing, opportunities for developing existing geophysical tools have opened up. This technology can bridge the gap to overcome various shortcomings and improve the functionality of geophysical instruments. Automation and the use of cloud storage systems can significantly improve the efficiency of the data acquisition process. The integration of this modern technology enables the development of more sophisticated and user-friendly instruments [5][6].

This study aims to develop a multi-channel smart resistivity meter system and conduct limited testing of the developed system. The resulting system design is expected to be implemented as an IoT-based resistivity meter capable of operating in Schlumberger, Wenner, and Dipole-Dipole configurations. The design selection and limited testing were conducted to reduce costs without compromising the research objectives. The optimization and implementation of new features are expected to make the data acquisition process more efficient.

**RESEARCH METHODOLOGY**

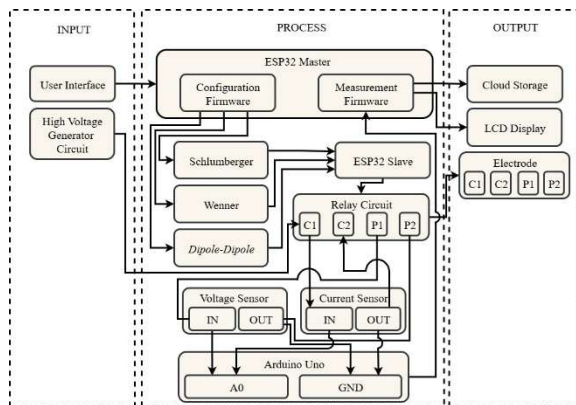
This work utilizes research and development approach implemented through system hardware design, system firmware design, system prototype development, and limited testing of a multi-channel smart resistivity meter system with eight electrodes.

**Multi-Channel Smart Resistivity Meter System Design Stage**

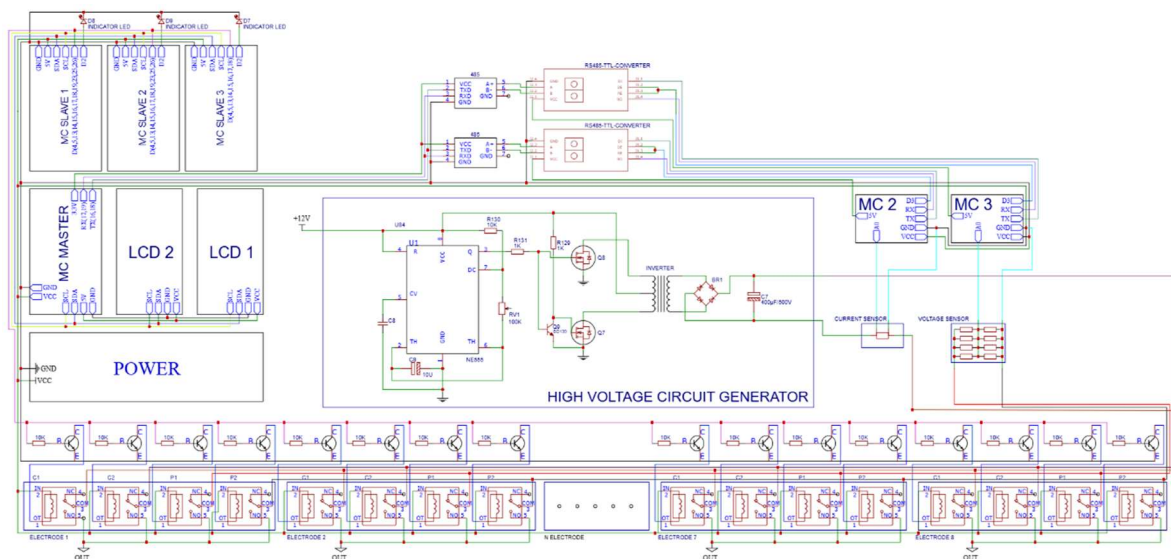
The design of this system began with the integration of several microcontroller modules to perform different functions. **Figure 1** is a block diagram visualization of the system to be created. This diagram shows a distributed control structure that divides the system into three main parts: input, process, and output. Each part illustrates the workflow and communication between components within the system.

In the input section, the system receives commands from the user interface (mobile application) and high voltage supply from the generator circuit. The commands are then processed by the ESP32 master and forwarded to control the electrode function in the relay circuit via the ESP32 slave. High voltage from the generator circuit input is supplied to the relay circuit as the system's high voltage source. Measurement is performed by Arduino uno by receiving signals from voltage and current sensors system. The data generated by Arduino uno is then forwarded to the ESP32 master. The results of this processing are then channeled to the output section, namely to the LCD screen for local display and to cloud storage for real-time data storage.

The ESP32 Master is the main microcontroller that functions as the brain of the system and is responsible for the main communication with the user interface application, data processing, and data transmission to Google Sheets-based cloud storage. Arduino Uno is the main microcontroller in the multi-channel smart resistivity meter measurement system. The Arduino Uno communicates serially with the ESP32 Master to send data acquired through communication with current and voltage sensors. The ESP32 Slave receives command from the ESP32 Master to control the relay circuit. The output of the relay circuit is set to follow the predetermined digital output of the microcontroller so that it can automatically switch electrodes according to the configuration selected by the user (Schlumberger, Wenner, or Dipole-Dipole).

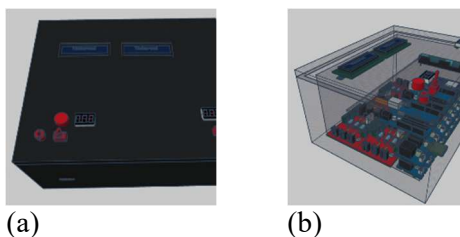


**Gambar 1.** Block diagram of a multi-channel smart resistivity meter system



**Figure 2.** Schematic of a multi-channel smart resistivity meter system

**Figure 2** shows the wiring diagram that implements microcontroller-based electrode control for the smart resistivity meter system. The system consists of three slave microcontroller units (MC SLAVE 1, 2, and 3) equipped with LED indicators for monitoring operational status, as well as one main microcontroller unit (MC MASTER) that functions as the system controller. The power supply circuit uses an inverter with a step-up transformer and rectifier bridge to generate the high voltage required by the electrodes, while communication between modules is carried out via an RS485-TTL converter to ensure stable data transmission. The physical monitoring system consists of an LCD display for the user interface, a separate power unit, and integrated current and voltage sensors for real-time monitoring of operational parameters. Each electrode has 4 main functions (C1, C2, P1, P2) with each PIN on the electrode equipped with a transistor driver and protection system, allowing independent control of each electrode to work optimally.

**Figure 3.** 3D design of multi-channel smart resistivity meter

**Figure 3** shows a 3D design of a smart resistivity meter that displays the physical implementation of the electrode control system that has been designed. The external part consists of black housing equipped with two LCD displays on the top panel for real-time monitoring of operational parameters. Meanwhile, the front panel contains communication ports for connectivity with electrode cables. The internal visualization shows the layout of the components, where the main PCB contains a microcontroller circuit and electrode drivers arranged in a layered configuration to optimize space usage.

### Software Design Stage (Firmware) for Multi-Channel Smart Resistivity Meter System

The firmware embedded in the microcontroller has three main functions, namely control logic,

data acquisition, and data communication. The control logic program contains the implementation of algorithms to switch the function of each electrode according to the Schlumberger, Wenner, and *Dipole-Dipole* configuration schemes. The data acquisition program contains programs for reading data from sensors, processing it, and performing calibrations to address any detected discrepancies. The data communication program manages data transmission from each microcontroller used locally and transmission to the associated cloud system via an internet connection. The data sent includes current and voltage values, as well as time and measurement configuration information.

### Prototype Development Stage of the Multi-Channel Smart Resistivity Meter System

This stage focuses on assembling electronic and mechanical components. The main components used include Microcontroller Module: Consisting of ESP32 Master, ESP32 Slave, and Arduino Uno. A Current Sensor designed based on a shunt resistor to measure the current injected into the test medium. A Voltage Sensor designed based on a voltage divider circuit to measure the potential between the potential electrodes. An Electrode Switching System using a Relay Module controlled by the ESP32 Slave for electrode configuration automation. A User Interface built using a mobile application based on MIT App Inventor. This application connects to the ESP32 Master via a wireless (Wi-Fi) connection to send commands and display the device status. Local Display Using two 16x2 LCDs to display real-time current and voltage measurement results to users in the field.

### Multi-Channel Smart Resistivity Meter System Testing Stage

A series of limited tests were conducted to validate the system's performance. First, a sensor test was conducted to test the accuracy of the current and voltage sensors to ensure accurate readings. Then, a functional test was conducted to test whether the system was able to switch electrodes correctly according to the selected configuration. Next, a Connection Test was conducted to ensure smooth communication between the mobile application, microcontroller, and cloud storage. Then, an Analysis of the

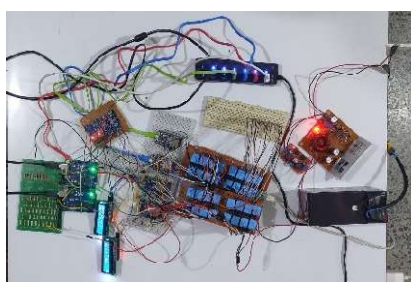
Results from the limited testing was conducted to determine the error and precision values of the device.

### Multi-Channel Smart Resistivity Meter System Flowchart

The system begins with an initialization process that includes setting up WiFi connections and serial communication between microcontrollers. After successful initialization, the system waits for configuration input from the user via a mobile application. When the user selects a measurement configuration (Schlumberger, Wenner, or *Dipole-Dipole*), the ESP32 Master sends a command to the ESP32 Slave. The ESP32 Slave then executes the program to switch the electrodes according to the selected configuration pattern.

## RESULTS AND DISCUSSION

The prototype multi-channel smart resistivity meter was successfully assembled and integrated into a single system, as shown in **Figure 4**. The system consists of several main modules, including ESP32 Master and Slave, Arduino Uno, a relay circuit for electrode switching, current and voltage sensors, and communication modules that are interconnected to form a distributed architecture. After assembly was complete, a series of limited tests were conducted to determine the performance of each component and the overall functionality of the system.



**Figure 4.** Results of assembling a prototype multi-channel smart resistivity meter system

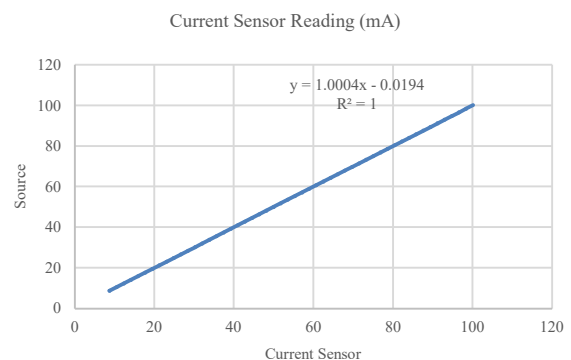
The output voltage of the smart resistivity meter system is 100 V with an error of  $\pm 0.2$  V, as shown in the measurement results in **Figure 5**. Measurements were taken with a multimeter to verify that the voltage produced was in accordance with the design specifications. The test results confirmed that the system could produce a relatively stable output voltage at the desired level with a good level of accuracy.



**Figure 5.** Smart resistivity meter system voltage output testing

### Current Sensor And Voltage Sensor Testing

The current sensor has a total resistance of approximately  $1.1 \Omega$  with a combined power rating of 5 watts. The microcontroller ADC uses a 1.1 volt voltage reference ( $V_{ref}$ ) to increase the resolution of the sensor readings. The current sensor was tested by varying the current input randomly at intervals of 0-100 mA and recording the resulting voltage response. The calibration function obtained was  $y = 1.0004x + 0.0194$  with an average relative error of 0% and an average absolute error of -0.00018. Sensor testing data was obtained using several random samples in the range of 0-100 mA measured using the MMD Sanwa CD800a. The test results graph is shown in **Figure 6** below.



**Figure 6.** Current sensor test chart

Then, the voltage sensor was designed using a voltage divider circuit with a ratio of 20:1. The resistance values used were  $R_1$  of 190.9 k $\Omega$  and  $R_2$  of 9.99 k $\Omega$ , resulting in a mathematical ratio of 20.10910911:1. The microcontroller ADC was tested with a voltage reference ( $V_{ref}$ ) of 5 V to maximize the reading range. From several samples of reading data compared with the Sanwa CD800a MMD at intervals of 0-100V, a calibration function of  $y = 1.0003x + 0.0122$  was obtained. **Figure 7** is a graph of the final sensor test results showing an

average absolute error of -0.001166667 and an average relative error of 0%.

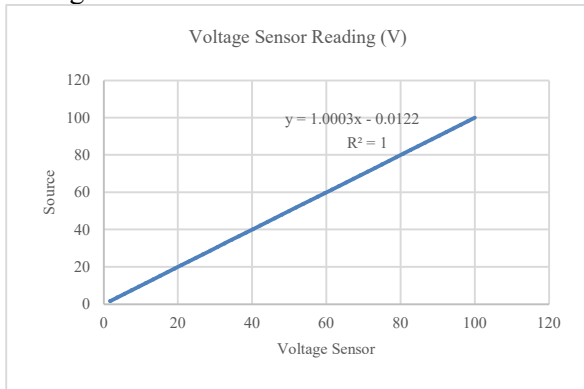


Figure 7. Voltage sensor test chart

After separate testing of each sensor, the sensors were assembled into the smart resistivity meter system and tested again. The results of observations of the response of the multi-channel smart resistivity meter measurement system are shown in **Figure 8(a)** for current readings and **Figure 8(b)** for voltage readings. The comparison graph between the smart resistivity meter readings and the MMD Sanwa CD800a readings shows a regression coefficient value close to one.

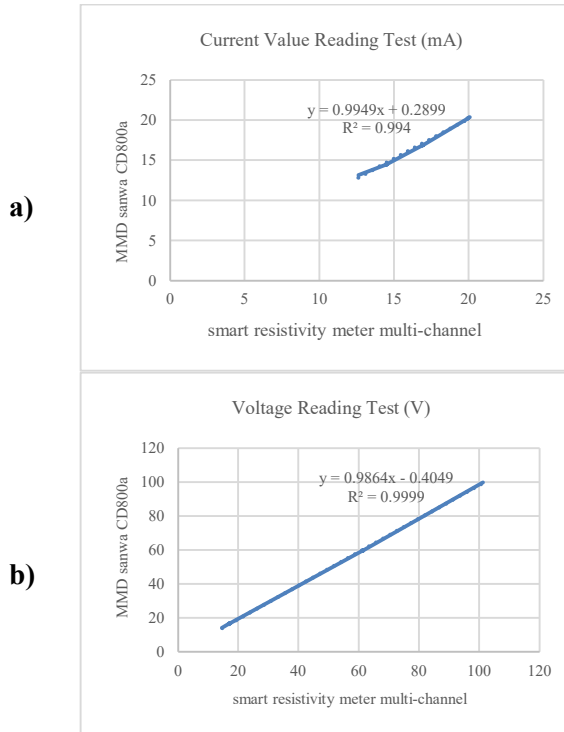


Figure 8. Results of testing the smart resistivity meter measurement system

The results obtained were an average relative error of 3% for current measurements

and 2% for voltage measurements from the multi-channel smart resistivity meter reading system. Based on the observation data, the average absolute error value for the current sensor was 0.2 mA, while for the voltage sensor it was 0.99 V. The precision level of the voltage measurement system was obtained at 92%, based on sample data at a voltage value of around 14.6 V. Meanwhile, the precision of the current measurement system was obtained at 96% based on sample data at a current value of around 14.5 mA.

### Electrode Switching Relay Firmware Testing

The program for electrode switching configuration was tested by observing the LED lights arranged in such a way as to represent each electrode in the switching process. The color of each LED was differentiated to visually indicate the working condition of the electrode. The green color on the left side of the electrode segment indicates the function as C1, while the green color on the right side indicates the function as C2. The red color is used to indicate the electrode that functions as P1, and the yellow color for the electrode that functions as P2. The LED circuit used to test the electrode configuration program logic is shown in **Figure 9**.

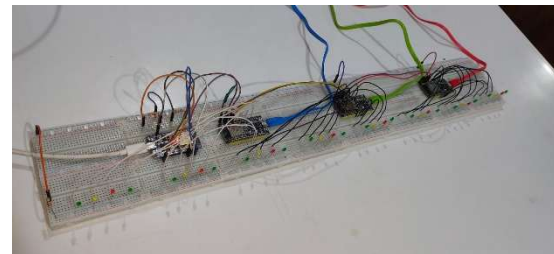


Figure 9. Smart resistivity meter logic test board

The system's operational logic was tested by connecting the microcontroller circuit to a test board, then uploading the logic program for each electrode configuration to the microcontroller to be executed according to the designed sequence. In the Schlumberger configuration, the test produced three observation data points indicating that the program ran as expected, where the electrode working logic sequence was displayed visually through LED indicators as shown in **Figure 10(a)**. Next, the Wenner configuration test was carried out by changing the program running on the microcontroller in accordance with the

Wenner configuration logic, which produced seven observation data and showed that the system functioned properly in accordance with the sequence shown in **Figure 10(b)**. Meanwhile, the Dipole-Dipole configuration test

successfully produced five observation data confirming that the program ran as expected, with the electrode working logic sequence observable through the LED light pattern as shown in **Figure 10(c)**.

Stage n	Electrode 1	Electrode 2	Electrode 3	Electrode 4	Electrode 5	Electrode 6	Electrode 7	Electrode 8
1	not lit	not lit	C1	P1	P2	C2	not lit	not lit
2	not lit	C1	not lit	P1	P2	not lit	C2	not lit
3	C1	not lit	not lit	P1	P2	not lit	not lit	C2

Stage n	Electrode 1	Electrode 2	Electrode 3	Electrode 4	Electrode 5	Electrode 6	Electrode 7	Electrode 8
1	C1	P1	P2	C2	not lit	not lit	not lit	Mati
2	not lit	C1	P1	P2	C2	not lit	not lit	not lit
3	not lit	not lit	C1	P1	P2	C2	not lit	not lit
4	not lit	not lit	not lit	C1	P1	P2	C2	not lit
5	not lit	not lit	not lit	not lit	C1	P1	P2	C2
6	C1	not lit	P1	not lit	P2	not lit	C2	not lit
7	not lit	C1	not lit	P1	not lit	P2	not lit	C2

Stage n	Electrode 1	Electrode 2	Electrode 3	Electrode 4	Electrode 5	Electrode 6	Electrode 7	Electrode 8
1	C1	C2	P1	P2	not lit	not lit	not lit	not lit
2	C1	C2	not lit	P1	P2	not lit	not lit	not lit
3	C1	C2	not lit	not lit	P1	P2	not lit	not lit
4	C1	C2	not lit	not lit	not lit	P1	P2	not lit
5	C1	C2	not lit	not lit	not lit	not lit	P1	P2

Figure 4. Results of testing the working logic of the smart resistivity meter

**Testing the Connectivity of the Mobile Interface and Cloud System with the Multi-Channel Smart Resistivity Meter System**

Figure 11 shows the mobile application interface that functions as a control system for multi-channel smart resistivity meter devices. This application is designed to connect mobile devices to physical instruments through the Transmission Control Protocol/Internet Protocol (TCP/IP) connection feature based on MIT APP Inventor in client-server mode. The main function of this application is to provide various options for configuring the main geophysical measurements, namely Wenner, Schlumberger, and Dipole-Dipole, as well as system status checking and testing of all configurations.

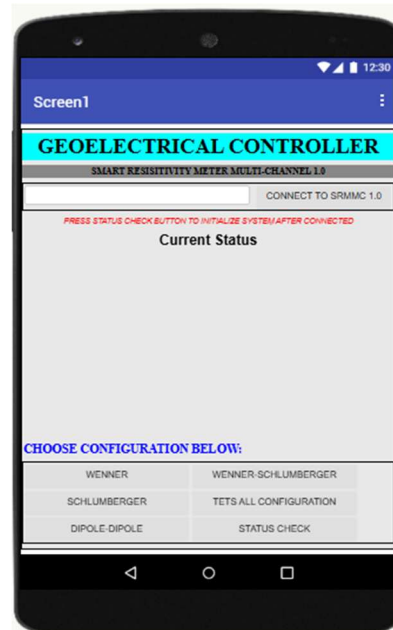
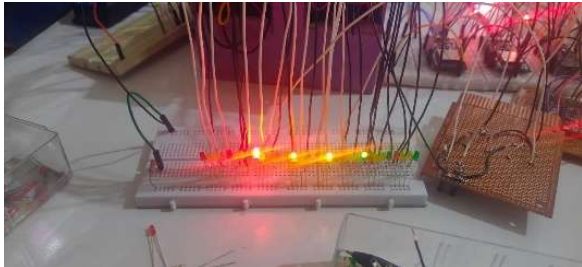


Figure 5. Mobile-interface smart resistivity meter

Testing the selection of each configuration using the buttons available on the interface application shows that the application works well. When the Schlumberger configuration button is selected, the system will run the Schlumberger configuration until the measurement process is complete. The same

applies to the Wenner, *Dipole-Dipole* configuration buttons, as well as the Status Check and test all configuration features. **Figure 12** below shows one of the testing processes in a series of interface application function tests on a multi-channel smart resistivity meter system.



**Figure 6.** Documentation of mobile interface connectivity testing with the smart resistivity meter system

Then, cloud connectivity testing was carried out by reviewing whether the measurement data could be sent and displayed automatically in Google Sheets. Based on the observations, the data was successfully uploaded in real time without any delays or loss of information, indicating that the cloud storage system was functioning properly and was optimally integrated with the multi-channel smart resistivity meter system. The final results of the cloud system that received data from the device are shown in Figure 13.

TimeStamp	Method	Stage	Config	C1_Electrode	P1_Electrode	C2_Electrode	Current_I(A)	Voltage_V	Resistance_Ohm	Success
2025-08-12 11:20:20	WENNER	1	1	1	2	3	4	7.92024	0	TRUE
2025-08-12 11:20:26	WENNER	1	2	2	3	4	5	7.67743	0	TRUE
2025-08-12 11:20:30	WENNER	1	3	3	4	5	6	10.5066	38.2096	TRUE
2025-08-12 11:20:35	WENNER	1	4	4	5	6	7	14.4976	101.281	TRUE
2025-08-12 11:20:39	WENNER	1	5	5	6	7	8	14.432	101.281	TRUE
2025-08-12 11:20:43	WENNER	2	1	1	3	5	7	14.3628	101.281	TRUE
2025-08-12 11:20:47	WENNER	2	2	2	4	6	8	14.4993	101.281	TRUE
2025-08-12 11:20:51	SCHLUMBERGER	1	1	3	4	5	6	14.4054	101.281	TRUE
2025-08-12 11:20:54	SCHLUMBERGER	1	2	2	4	5	7	14.4068	101.281	TRUE
2025-08-12 11:20:58	SCHLUMBERGER	1	3	3	4	5	8	14.4034	101.281	TRUE
2025-08-12 11:21:04	DIPOLE-DIPOLE	1	1	1	3	4	2	14.471	101.281	TRUE
2025-08-12 11:21:08	DIPOLE-DIPOLE	1	2	1	4	5	2	14.426	101.281	TRUE
2025-08-12 11:21:12	DIPOLE-DIPOLE	1	3	1	5	6	2	14.4805	101.281	TRUE
2025-08-12 11:21:20	DIPOLE-DIPOLE	1	4	1	6	7	2	14.4775	101.281	TRUE
2025-08-12 11:21:27	DIPOLE-DIPOLE	1	5	1	7	8	2	14.51	101.281	TRUE

**Figure 7.** Display of measurement data from the smart resistivity meter

**CONCLUSION**

Based on the results of the design and testing of the multi-channel smart resistivity meter that has been carried out, a multi-channel smart resistivity meter was successfully designed and implemented using a combination of an ESP32 microcontroller as the master and three other ESP32s as slaves that communicate with each other via the I2C protocol. This system is

capable of automatically controlling 8 electrodes with Schlumberger, Wenner, and *Dipole-Dipole* measurement configurations.

The current and voltage measurement system was successfully developed with an average relative error of 3% for voltage measurements and 2% for current measurements, with a system precision of 92% for voltage and 96% for current in the working range of 0-100 V and 0-100 mA. The measurement data was successfully stored on the Google Sheets-based cloud system in real time.

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