The Development of a Small Range Soil Electrical Resistivity Meter Based on Wenner Configuration

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Abstract — **Soil resistivity analysis is one of the important fundamentals in practicing precision agriculture and exploring subsurface structure of a region. Most of the existing resistivity tools are not suitable for small scale resistivity measurement due to their bulky size. This paper presents the development of soil electrical resistivity meter which suits for small range resistivity measurement. A method is presented for constructing an apparatus for measuring electrical resistivity in both tabletop laboratory setting and in the field. The findings of the resistivity test in the planter box (15cm x 42cm) are discussed in this paper. The experiments were conducted with varies distance setting as well as for two different samples of soil; brown and black, which were also tested for wet and dry conditions. Wenner configuration method was implemented in this experiment for its advantages compared to the other arrays. A comparison of the results indicates possible variation of soil resistivity for different types and conditions of soil over small distances.**

Keywords - soil resistivity; conductivity; Wenner array; Ohm's law; direct current (DC)

I. INTRODUCTION

Electrical underground parameters can be typically obtained by using electrical methods such as electrical resistivity tomography (ERT), electrical resistivity imaging (ERI), induced polarization (IP) and magnetotellurics (MT). Common parameters that can be measured by these methods are resistivity, conductivity and chargeability which are useful in determining types of soil, analyzing water content and also in mineral exploration [1].

The main objective of soil resistivity testing is to determine the soil conductivity by measuring a volume of soil. Electrical conductivity (EC) can be defined as the ability of a material to conduct an electrical current and is expressed in Siemens per meter (S/m). All soils conduct electrical current but the conductivity is varies depending on the moisture content of the soils. For example, sands have a low conductivity while silts and clays have a medium and high conductivity respectively. Therefore, EC is strongly influenced by the soil particle size and texture [2].

One of the fundamentals in resistivity measurement is an electrode array which represents the configuration setting of electrodes used to measure electric current or voltage [3]. There are various electrode configurations applicable for measuring soil resistivity such as Wenner, Schlumberger, pole-dipole and dipole-dipole. Each of these electrode arrangements has its own advantages and disadvantages, depending on the type of survey to be performed. Some of these arrangements are shown in Fig. 1.

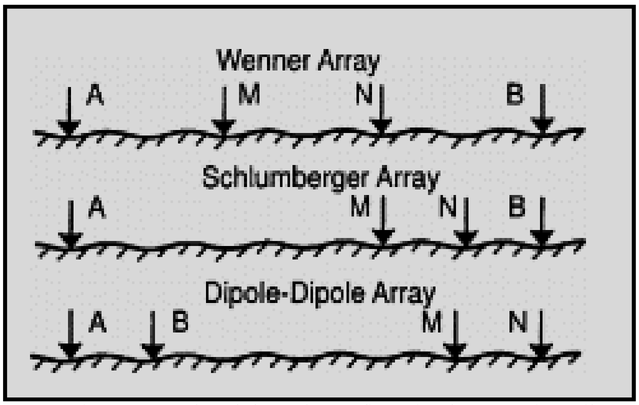

Fig. 1 Examples of electrodes configuration for measuring soil resistivity [3].

In this project, Wenner array has been considered for measuring soil resistivity due to its efficiency in terms of the ratio of received voltage per unit of transmitted current compared to the other arrays [4]. Besides that, this array has the simplest geometry, with all of the electrodes are injected into the ground with same distance between one another as can be seen in Fig. 2. Furthermore, the formula to obtain the apparent value of resistivity for Wenner array is not that complex and hence it is easily calculated [5].

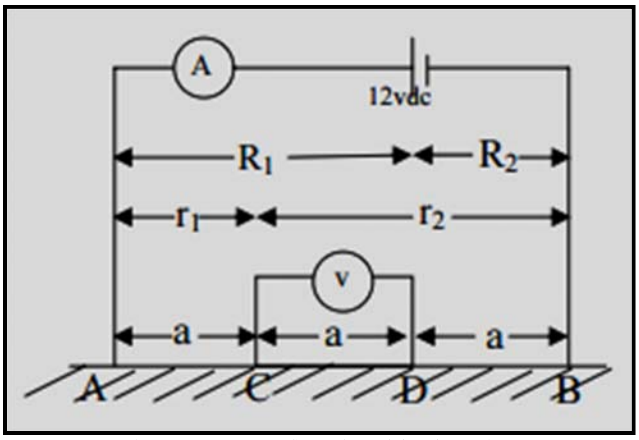

Fig. 2 Wenner configuration of the electrodes [5].

Ohm's Law explains the electrical properties of any medium. The equation relates the voltage with the product of current and the resistance.

$$V = IR \tag{1}$$

Resistivity can be defined as a change in scale of resistance by the ratio of a cross-sectional area and unit length of the material. The SI unit of resistivity is ohm-meter (Ωm) and is the reciprocal of the conductivity of the material [6].

The resistance can be obtained by considering a cylindrical material of resistivity, ρ, length, L, and cross sectional area, A. Thus,

$$R = \frac{\rho L}{A} \tag{2}$$

and

$$\rho = \frac{RA}{L} \tag{3}$$

As shown in Fig. 2, the potential difference applied across electrodes A and B in which current is injected through them is dispersed throughout the region between them while the potential difference for a semi-infinite earth or uniform resistivity, ρ, between electrodes C and D is expressed by [7],

$$\Delta V = VC - VD \tag{4}$$

Therefore, the voltage at electrodes C and D can be calculated by,

$$VC = \frac{\rho L}{2\pi}\left(\frac{1}{r1} - \frac{1}{r2}\right) \tag{5}$$

and

$$VD = \frac{\rho L}{2\pi}\left(\frac{1}{R1} - \frac{1}{R2}\right) \tag{6}$$

The voltage measurement can be measured by using the voltmeter across the electrodes C and D as in equation (3),

$$V = \frac{\rho L}{2\pi}\left(\frac{1}{r1} - \frac{1}{r2}\right) - \frac{\rho L}{2\pi}\left(\frac{1}{R1} - \frac{1}{R2}\right) \tag{7}$$

Hence, the measured apparent resistivity can be retrieved from,

$$\rho_a = \frac{2\pi\Delta V}{I\left\{\left(\frac{1}{r1}-\frac{1}{r2}\right)-\left(\frac{1}{R1}-\frac{1}{R2}\right)\right\}} \tag{8}$$

where r1= R1 and r2= R2 as shown in Equation (5). So,

$$\rho_a = \frac{2\pi\Delta V}{I\left\{\left(\frac{1}{a}-\frac{1}{2a}\right)-\left(\frac{1}{2a}-\frac{1}{a}\right)\right\}} \tag{9}$$

Therefore,

$$\rho_a = \frac{2\pi a\Delta V}{I} \tag{10}$$

in which

$$R = \frac{V}{I} \tag{11}$$

Hence,

$$\rho_a = 2\pi aR \tag{12}$$

From the above equations, the apparent resistivity is assumed to be uniform within the soil and therefore, the apparent resistivity can be treated as equal to the true value of resistivity [7].

This paper highlights on the designing of soil resistivity meter based on Wenner configuration for small range resistivity measurement. The aim of this study is to test the workability of this small range soil electrical resistivity meter by experimenting it for several variables. The measured resistivity data from the developed resistivity meter are discussed and analyzed.

II. METHODOLOGY

In this part of research, there are two stages of methodology in developing this resistivity meter. The first stage is the hardware design of small range soil electrical resistivity meter followed by its evaluation by testing it for two types of soil with different conditions.

A. Hardware Design

The basic instruments used for constructing the resistivity meter are extremely simple. The circuit connection was done by referring to the block diagram as shown in Fig. 3.

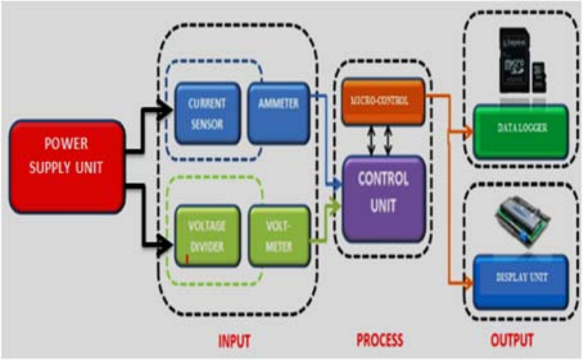

Fig. 3 Block diagram of overall design of the soil resistivity meter.

1) *Input Part*

For direct current (DC) resistivity survey, energy source is a generator in which current is injected into the ground by using two electrodes. The electrodes were connected directly into two main inputs which are ammeter and voltmeter. DC battery was used in this development of resistivity meter to make it independent to bring everywhere without thinking the alternate current (AC) source and the need to use long cable connection.

In this project, two lithium acid battery of 12V with 7000mA were used and attached to the step up module in order to increase the power supply into 60V. By using simple concept of Ohm’s Law, current is directly proportional to the voltage. Therefore, by increasing the voltage, current can be increased too [8]. This is crucial as high current is needed to be injected into the ground so that the grounding losses can be reduced.

The outer part or transmitter part of the electrodes is the pair of current injection as shown in Fig. 2. The ACS712 current sensor module was used in this project as it provides economical and precise solutions for DC current sensing measurement.

The inner part of the connected electrodes is the receiver part which measures the voltage as current is injected into the ground. In this case, underground soil acts as a resistor.

2) *Process Part*

The process or microcontroller part is actually the main part in making this resistivity meter. This part controls all activities from input until the output. Arduino Uno Compatible was used in this project which consists of 13 input and output parts. A microcontroller, Arduino Uno, was used to measure the reading of voltage.

3) *Output Part*

Next, the output parts which are a liquid-crystal display (LCD) Keypad Shield and secure digital (SD) Card module were connected to the microcontroller where both parts display the reading of the soil resistivity and save the measured data respectively.

B. *Prototype Testing*

After completed the hardware design part, the developed resistivity meter must be tested in order to determine the workability of this resistivity meter. For that reason, a series of experiment has been carried out by measuring soil resistivity of two types of soil which are black soil and brown soil for different conditions.

The composition of black soil consists of top soil, coco peat, black ash and compost while brown soil contains 0.15% of Nitrogen (N), 0.50% of Phosphorous (P), 0.30% of Potassium (K) and 0.15% of Magnesium Oxide (MgO). In addition to that, 500 ml of water was added to each type of soil to observe soil resistivity when there is influence of water.

As depicted in Fig. 4, four electrodes at equal distance were injected at arbitrary point into the planter box with the size of 15cm height times with 42cm length. The resistivity meter was then connected to the four electrodes by using wires. Next, an external voltage was applied and current was injected across the two outer electrodes so that soil resistivity can be obtained from the potential difference between the inner electrodes. The distance was then varied by changing the electrode spacing from 0.03m until 0.14m.

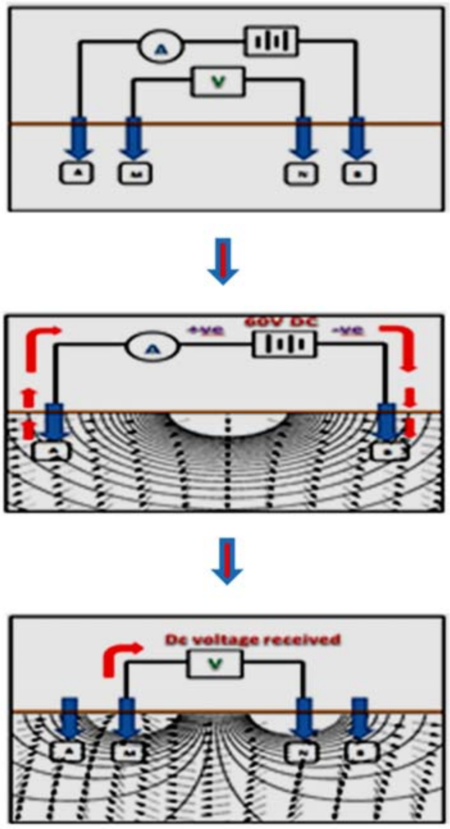

Fig. 4 Steps in measuring soil resistivity.

III. RESULT AND DISCUSSION

Table I until Table IV show the resistivity reading measured for different types and conditions of soil; dry black soil, wet black soil, dry brown soil and wet brown soil. A graph is then plotted for each table as depicted in Fig. 5 until Fig. 8.

A. *Experiment 1: Dry Black Soil*

TABLE I. RESISTIVITY READING FOR DRY BLACK SOIL

Electrode spacing (m)	***Voltage (V)***	***Current (mA)***	***Resistance (Ω)***	***Resistivity (Ωm)***
			R = V/I	***2πaR***
0.03	8.14	4.25	1915.29	361.02
0.04	4.58	3.35	1367.16	343.61
0.05	5.84	3.11	1877.81	589.93
0.06	9.7	4.53	2141.28	807.24
0.07	9.92	4.15	2390.36	1051.34
0.08	12.81	4.56	2809.21	1412.06
0.09	13.04	4.34	3004.61	1699.07
0.10	11.47	3.96	2896.46	1819.90
0.11	11.66	3.48	3350.57	2315.75
0.12	10.55	3.15	3349.21	2525.24
0.13	12.13	3.20	3790.63	3096.24
0.14	12.17	3.24	3756.17	3304.10

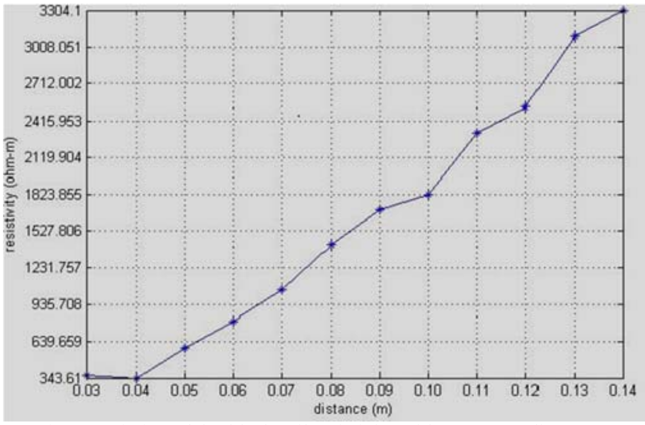

Fig. 5 Variation of dry black soil resistivity with respect to distance.

B. *Experiment 2: Wet Black Soil*

TABLE II. RESISTIVITY READING FOR WET BLACK SOIL

Electrode spacing (m)	***Voltage (V)***	***Current (mA)***	***Resistance (Ω)***	***Resistivity (Ωm)***
			R= V/I	***2πaR***
0.03	6.41	33.4	191.92	36.18
0.04	8.8	29.4	299.32	75.23
0.05	10.11	35.8	310.06	97.41
0.06	11.51	36.0	319.72	120.53
0.07	11.36	38.1	298.16	131.14
0.08	10.45	28.8	362.85	182.39
0.09	10.34	27.9	370.61	209.57
0.10	10.39	25.3	410.67	258.03
0.11	9.20	21.3	431.92	298.53
0.12	12.12	23.5	515.74	388.86
0.13	12.8	23.7	540.08	441.15
0.14	14.46	21.8	571.56	502.77

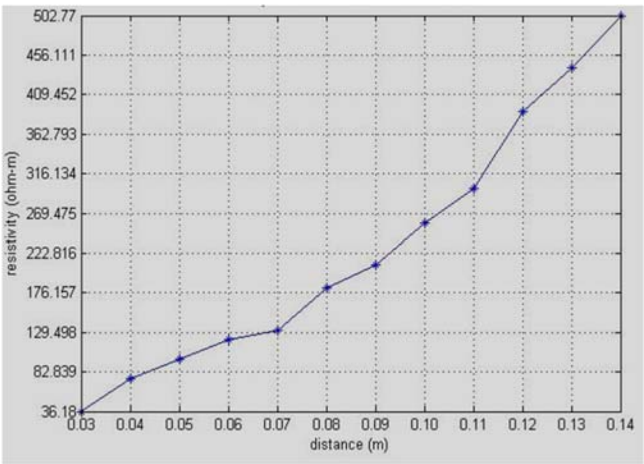

Fig. 6 Variation of wet black soil resistivity with respect to distance.

C. *Experiment 3: Dry Brown Soil*

TABLE III. RESISTIVITY READING FOR DRY BROWN SOIL

Electrode spacing (m)	***Voltage (V)***	***Current (mA)***	***Resistance (Ω)***	***Resistivity (Ωm)***
			R= V/I	***2πaR***
0.03	10.11	55.9	180.86	34.09
0.04	11.57	53.1	217.89	54.76
0.05	12.58	46.5	270.54	84.99
0.06	12.9	39.4	327.41	123.43
0.07	12.99	36.1	359.83	158.26
0.08	11.14	27.8	400.72	201.42
0.09	15.18	32.4	468.52	264.94
0.10	13.69	27.0	507.04	318.58
0.11	15.55	29.0	536.21	370.6
0.12	14.12	24.0	588.33	443.59
0.13	15.06	24.2	622.31	508.31
0.14	15.86	22.5	704.89	620.05

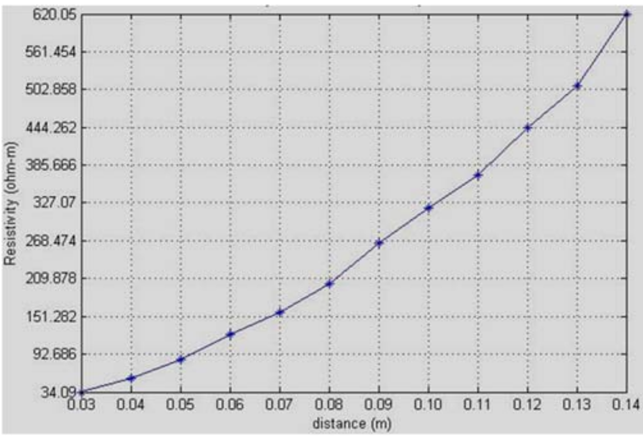

Fig. 7 Variation of dry brown soil resistivity with respect to distance.

D. *Experiment 4: Wet Brown Soil*

TABLE IV. RESISTIVITY READING FOR WET BROWN SOIL

Electrode spacing	*Voltage*	*Current*	***Resistance (Ω)***	***Resistivity (Ωm)***
(m)	*(V)*	*(mA)*	***R= V/I***	***2πaR***
0.03	8.69	153.8	56.50	10.65
0.04	10.84	146.2	74.15	18.63
0.05	10.54	125.8	83.78	26.32
0.06	11.46	116.0	98.79	37.24
0.07	11.95	108.7	109.94	48.35
0.08	14.00	96.4	145.23	73.00
0.09	14.20	92.7	153.18	86.62
0.10	14.13	84.9	166.43	104.57
0.11	13.63	76.3	178.64	123.46
0.12	15.20	75.3	201.86	152.2
0.13	14.24	68.3	208.49	170.3
0.14	15.98	68.0	235.00	206.72

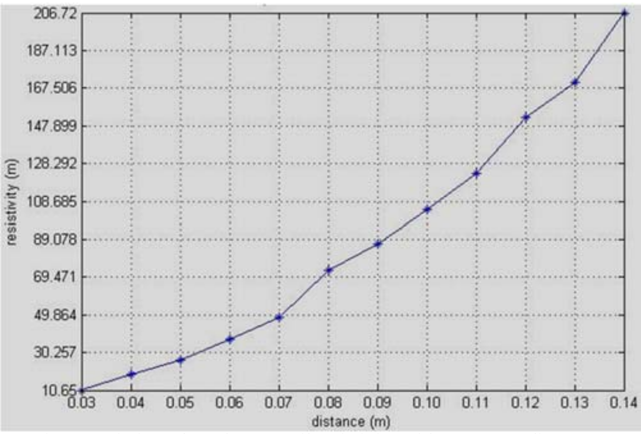

Fig. 8 Variation of wet brown soil resistivity with respect to distance.

E. *Analysis of The Measured Soil Resistivity and Conductivity*

Based on the results obtained, it can be seen that the resistivity reading varied for different types and conditions of soil. Furthermore, the resistivity reading also showed variations as the distance changed. Table V presents the average reading of soil resistivity and conductivity for different types and conditions of soil.

TABLE V. AVERAGE READING OF SOIL RESISTIVITY AND CONDUCTIVITY

Types and Conditions of Soil	**Average Resistivity (Ω m)**	**Average Conductivity (mS/m)**
Dry black soil	1610.46	0.62
Wet black soil	228.48	4.38
Dry brown soil	262.75	3.81
Wet brown soil	88.17	11.34

From Table V, wet brown soil showed the lowest average reading of resistivity which is 88.17Ωm that corresponds to highest average reading of conductivity which is 11.34mS/m. This represents that wet brown soil has better conductivity compared to the other types of soil due to the presence of water. Meanwhile, dry black soil records the highest average reading of resistivity in which indicates poor conductivity of the soil.

From this analysis of soil resistivity and conductivity, the percentage different between the same type of soil with different condition was also calculated. The percentage different between wet brown soil and dry brown soil (% diff_{brs}) is obtained from,

$$\% \, diff_{brs} = \frac{11.34 - 3.81}{15.15} \; x \; 100 = 49.7 \, \%$$

Meanwhile, the percentage different between wet black soil and dry black soil (% diff_{bls}) is,

$$\% \, diff_{bls} = \frac{4.38 - 0.62}{5} \; x \; 100 = 75.2 \, \%$$

From the calculation above, brown soil shows lower percentage different compared to black soil. This proves that brown soil has better conductivity than the black soil as its percentage different between wet brown soil and dry brown soil is lower.

IV. CONCLUSION

In summary, the results obtained from the prototype testing of this small range soil electrical resistivity meter have shown variations in the resistivity reading as it being tested for different types and conditions of the soil. The results of this study indicate the workability of this soil electrical resistivity meter. As this is the first stage in developing small range soil electrical resistivity meter, further experimental investigations need to be carried out in order to validate the data from this fabricated resistivity meter. Farmers, agronomists and geophysicists would find this small range soil electrical resistivity meter is practical to use for small scale measurement and low-cost as it uses simple electronic components compared to the established resistivity meter in the market.

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