International Journal of u- and e- Service, Science and Technology
Vol.9, No. 11 (2016), pp.307-316
http://dx.doi.org/10.14257/ijunesst.2016.9.11.27

Harmless Measurement of Tree Root Distribution Using Electrical Resistivity Method

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Abstract

The trees are of great meaning to the life and daily life of the human beings in various fields. However, the trees would disturb the normal activities of peoples. One of the problems is the growth of the tree roots close to the buildings or the roads can cause directly or indirectly structural damages. In this paper, a electrical measurement method based on resistivity is proposed The electrical property of tree root is analyzed. Finally, a tree root measurement system is built and practically tested.

***Keywords**: Electrical Exploration, Resistivity, Tree Root Zone*

1. Introduction

Within more and more modern constructure built, The necessities arise of a diagnostic tool to assess the distribution of the root system and their time-spatial growth as well. Invasive assessment and measurement of the tree root system in the underground conditions is very difficult, especially the big trees whose root system is extremely large and complex. The measurement of root zone has already been researched by many engineers and scientists and some achievement has been practically utilized. Tapani Repo introduces the structure of the plant and the electronic simulation of the plant in the "Physical and Physiological Aspects of Impedance Measurement in Plants" [1]. Ludek Aubrecht proposes the structure of the tree root and gives the theoretical method of calculating the absorption zone and identifying the distribution of tree root which depends on the soft, fine roots. Therefore, one electrical method is proposed to sketch the distribution of the tree root and find the area of absorption [2]. Another modification and test result of the system is also given by Ludek Aubrecht in a following article [3].

However, most of the currently available methods to access the tree root are harmful to the tree itself. The non-destructive evaluation of the plant root system is a challenge in root research.

Electrical technique of exploration geophysics is a good way to finish this task. It has long been a efficient way to obtain the characteristics of the subsurface from the surface which could be applied in verities of fields including detecting the appearance of the minerals, mapping the underground building sites, underground water investigations and so on. Dr. M. H. Loke introduces different methods used in the electrical exploration depending on the frequency of signal used and the distribution of the electrodes. The basic theory, theoretical calculation and result of these methods are demonstrated in the "Electrical Imaging Surveys for Environmental and Engineering Studies" [4]. Electrical Resistivity Tomography (ERT) [5] and the Ground Radar Penetrating (GRP) [6] are of great interest toward this issue as they could detect and identify the root system with very high resolution images in a non invasive way [7]. However, up to now, both of these two methods are expensive, time-consuming and with low efficiency. Therefore, efficient,

ISSN: 2005-4246 IJUNESST

time-saving and inexpensive method is highly desired for approximately estimating the tree root zone when the resolution of the image is not very demanding.

In this paper, a circuit based on symmetric quadruple method which belongs to the induced polarization is built. The AC current signal is induced into the ground through two current electrodes and the potential is obtained from the other two voltage electrodes. According to the measured voltage and the current and the relating formula, the apparent resistivity could be calculated. From the multi-times measurement and calculation of the resistivity on a geophysical profile, the distribution and the structure of the profile could be accurately sketched. The Figure 1 shows the basic structure of the equipment.

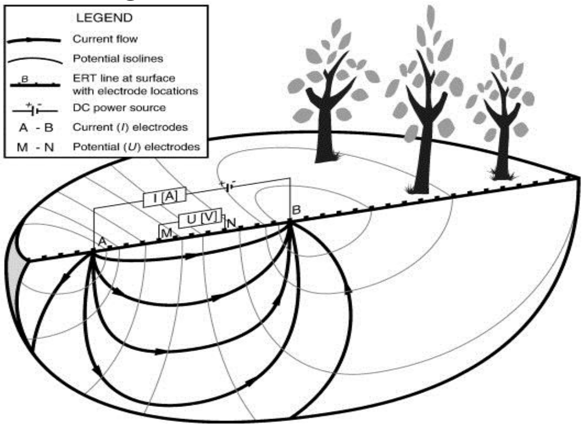

Figure 1. Basic Structure of the Equipment (Picture is Taken from

2. Basic Theory

2.1. Electrical Exploration

Apparent resistivity ρ is a general reflection of varieties of resistivity of different materials. The variation of ρ is closely related to the existence of uneventfully distributed objects. So the accurate calculation of the apparent resistivity is crucial. The Figure 2 demonstrates the specification of the built ground electrical field. The potential of random point could be calculated as below.

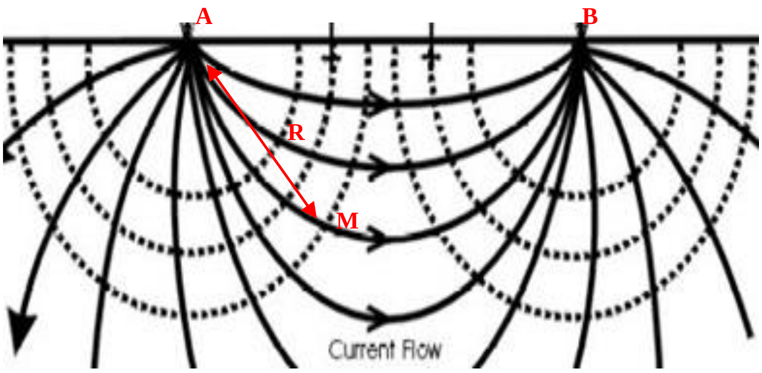

Figure 2. Ground Electrical Field

$$j = \frac{I}{2\pi R^2} \quad (1)$$

$$E = \rho j = \frac{I\rho}{2\pi R^2} \quad (2)$$

$$U = \int_{\infty}^{M} \frac{I\rho}{2\pi R^2} dr = \frac{I\rho}{2\pi R_M} \quad (3)$$

$$U_M = U_M^A + U_M^B = \int_{\infty}^{M} \frac{I\rho}{2\pi R^2} dr = \frac{\rho I}{2\pi}\left(\frac{1}{AM} - \frac{1}{BM}\right) \quad (4)$$

The Figure 3 demonstrates basic model of the symmetric quadruple method. The apparent resistivity could be calculated as below. The AC current signal is inserted into the ground system through electrodes A and B. The respond potential signal is obtained from the voltage electrodes M and N.

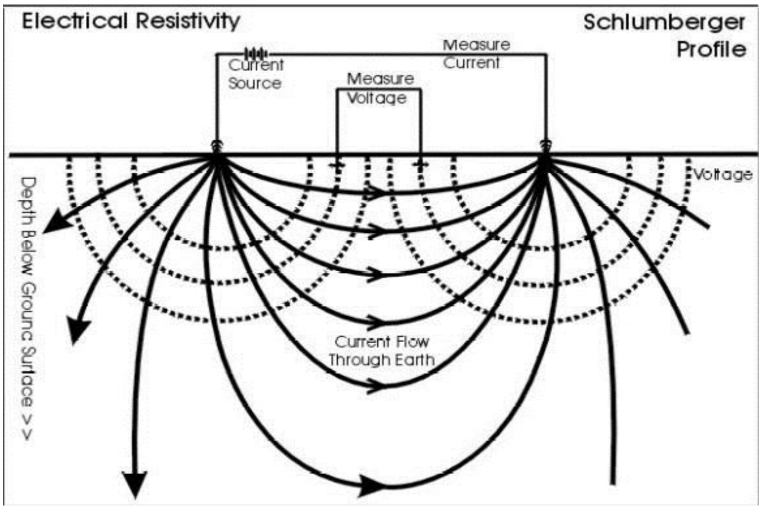

Figure 3. Basic Model of Symetric Quadrupole Method

$$U_M = \frac{\rho I}{2\pi}\left(\frac{1}{AM} - \frac{1}{BM}\right) \qquad U_N = \frac{\rho I}{2\pi}\left(\frac{1}{AN} - \frac{1}{BN}\right) \quad (5)$$

$$\nabla U_{MN} = U_M - U_N = \frac{\rho I}{2\pi}\left(\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right) \quad (6)$$

$$\rho = \frac{\nabla U_{MN}}{I} K \qquad K = \frac{2\pi}{\left(\frac{1}{AM} - \frac{1}{BM} - \frac{1}{AN} + \frac{1}{BN}\right)} \quad (7)$$

From the measurement and calculation of the resistivity on a profile, the distribution and structure of the different material could be identified and imaged.

2.2. Tree Root System

The method presented in this project focuses on the quantification of absorbing root surfaces through an electrical method. It is based on the fact that an applied electric current flows from the roots to the soil through the same interfacial areas and predominantly in the same way as flows from the soil to the tree. Based on the different resistivity of the tree tissues and soil, the interfacial area, which represents the absorbing root surfaces, can be calculated. The length of each root segment could also be obtained from the voltage curves and thus the distribution of the root system.

Figure 4 demonstrates the specification structure of a root segment. The root branches within the root envelop are of 2 kinds; Fine, soft root that absorbs the sap and water from the surrounding soils and think, wooden roots that transports the sap to the trunk and leaves. The soft, fine roots (1 in Figure 4) are electrically conductive with very low resistivity which can be seen as a conductor. The thinker, isolated roots (2 in the Figure 4) are electrically resistive with very high resistivity. The soft, fine roots usually located at the end of the whole root segment. So the length of the root segment and the absorption zone could be obtained by identifying the soft, fine root of the root segment.

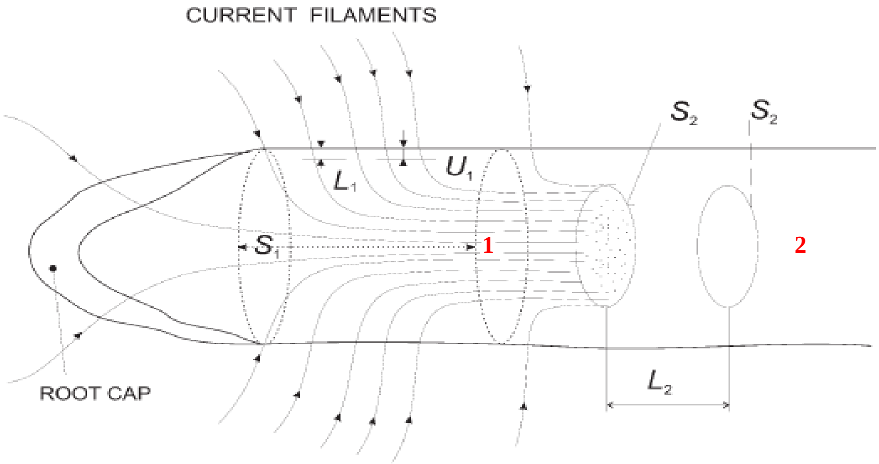

Figure 4. Specification of Root System

In Figure 4, S_1 Represents the absorption area, S_2 represents the cross-section zone of the root, L_1 represents the thickness of the absorption zone, L_2 and represents the length of the root segment. The formula of the absorption zone is shown as below:

$$I = \frac{U_1}{R_1} = \frac{U_2}{R_2} = \frac{U_1 S_1}{L_1 \rho} = \frac{U_2 S_2}{L_2 \rho} \quad (8)$$

$$S_1 = \frac{I}{U_1} \rho L_1 \quad (9)$$

$$S_2 = \frac{I}{U_2} \rho L_2 \quad (10)$$

On the basis of continuity, the current that flows through the absorption root surface also flows through the water-conducting cross-section zone at the same time. Therefore, S_1 and S_2 should be approximately equal.

$$S_1 = S_2 \quad (11)$$

Because the fine, soft roots are electrically conductive and have very low resistivity, they can be seen as good conductor. According to the basic theory that the conductor could be seen as an object with equal potential and the equal potential surface has the same configuration with the shape of the object, the fine, soft part of the root system can also be approximately seen as an object with the same potential on the surface. So the potential curve on this part remains constant or varying linearly with a very small slope. So, ratio of U_2 and L_2 remains constant.

$$S_1 = S_2 = \frac{I}{U_2^*} \rho L_2^* = \frac{I}{U_2^{**}} \rho L_2^{**} \quad (12)$$

$$S_{AZ} = \frac{\rho_{wood} L_{mean} U}{I} \quad (13)$$

S_{AZ} Represents the absorption zone of the tree root system, ρ_{wood} represents the resistivity of the tree root, L_{mean} represents the average length of the one root segment which could be seen as the distribution of the tree root system in one direction, U represents the measured voltage and I represents the measured current.

3. Theoretical Analysis and Results

The basic model of the root zone measuring equipment is based on the charge method usually used in explore object with good conductivity underground. It is kind of a traditional earth resistivity method.

The charge method is on the physical foundation that the charged object is relative conductive to the surrounding material, exploring the distribution and configuration and some other characteristics of the charged object through analyzing the distribution of the electrical field built artificially by the charged object. First of All, the electrical field built by the ideal charged conductor has no relationship with the charging position. It is only related to the strength of the charging current, the position of the conductor, the configuration of the object and the electrical characteristics of the surrounding material. Second, if the resistivity of the surrounding material is eventfully distributed, the charged object is of equal potential on every point of the surface and the equapotential surface distributed in the space has the similar configuration as the outline of the charged object. The degree of similarity decreases with the increase of the distance from the charged object. When the distance is large enough, the equapotential surface could be treated as a ball. Third, when the charged object is ideal conductor, the potential curve will reach the extreme value in the center of the conductor and reduce with the increase of the distance from the center point. The potential gratitude curve will have extreme value near the boundary of the charged object and the surrounding material. Finally, When the charged object is not ideal conductor, the potential difference will appear inside the conductor. The distribution of the built electrical field will thus also relate to the resistivity of the conductor and the charging position. When the charging position is on the side of the conductor, the potential curve reaches the extreme value at the charging position and reduces with the distance from the charging position. The potential gratitude curve also reaches the extreme value at this position.

As previously discussed, the root could be divided into two parts, the fine, soft roots and the thinker roots. The Thinker roots has very high resistivity and could be seen as isolator and the soft, fine roots is electrically conductive and could be seen as good conductor related to the surrounding ground. Therefore, when one electrode is inserted into the stem of the tree, the tree could be seen as one current electrode and the soft, fine part of the root could be seen as a charged object. The basic model of the tree root system is demonstrated in the Figure 5 (a) and the corresponding potential curve is demonstrated in the Figure 5 (b).

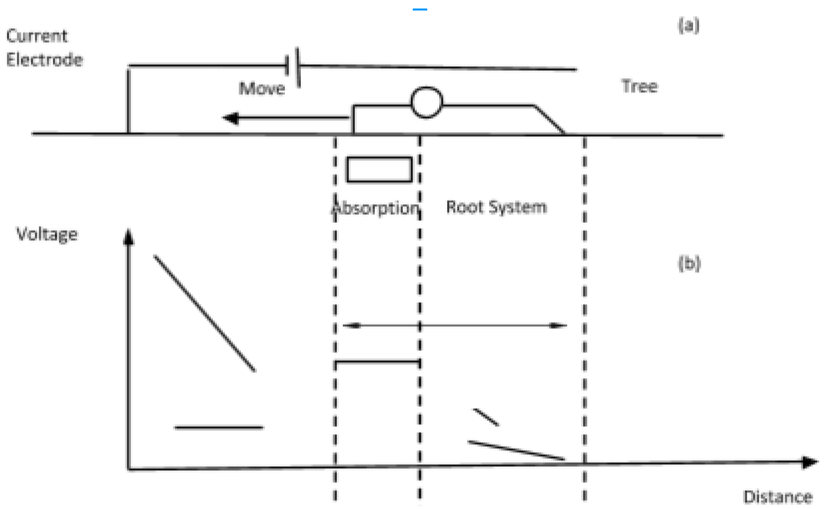

Figure 5. Basic Model and Potential Curve

According to the formula $S_{AZ} = \frac{\rho_{wood} L_{mean} U}{I}$ discussed in basic theory. ρ_{wood} Represents the resistivity of the tree system. The value of ρ can be obtained by measuring ρ in any part of stems or coarse roots associated with the given root segment. The formula of the resistivity of the tree is shown as below.

$$R_{MN} = \rho_{wood}\frac{p}{s} \rightarrow \rho_{wood}p = s\frac{U_{mn}}{I} \tag{14}$$

$$s = \frac{\pi D^2}{4} \tag{15}$$

$$\rho_{wood} = \frac{\pi D^2 U_{mn}}{4pI} \tag{16}$$

L_{mean} Represents the average length of one root segment in one direction. The average length L could be determined by the potential curve obtained from the measurement of voltage. Because the fine, soft roots could be seen as an object of same potential, the potential would increase greatly on the interface between fine roots and woody roots and the interface between the fine roots and the soil. Therefore, two extreme values would appear near these two interfaces in the curve of the gratitude of the potential changing rate which is the two times differential equation of the potential curve. The extreme large value will appear near the interface between the fine, soft root and the think isolated root. The extreme small value will appear near the boundary of fine, soft roots and the ground. Therefore, the average length could be obtained by finding the average length of the two extreme points.U and I represents the measured voltage and current. They could be obtained by calculating the average voltage and current above the fine, soft parts of the root in the potential curve.

After obtaining the average absorption zone of all the root segments in different direction around the tree stem (A constant degree between each direction). The total absorption zone could be obtained by summing up the absorption zone of each root segment.

$$A_{root} = \sum_{i=1}^{Direction} A_i \tag{17}$$

4. Hardware Design

The hardware of the tree root zone measurement system could be divided into two parts. One part is for signal processing, include A/D convertor to convert the digital driven signal generated by Matlab and the collected analog signal, power amplifier to amplify the driven signal and Rowarski coil to sense the collected voltage and current signal. Another part is responsible for electrodes changing which is responsible for automatically changing the target electrodes. It includes a Microcontroller to communicate with laptop through RS232 to coordinate with the signal processing part and send command to the multiplexer to change the electrodes. The diagram of the hardware connection is demonstrated in the Figure 6.

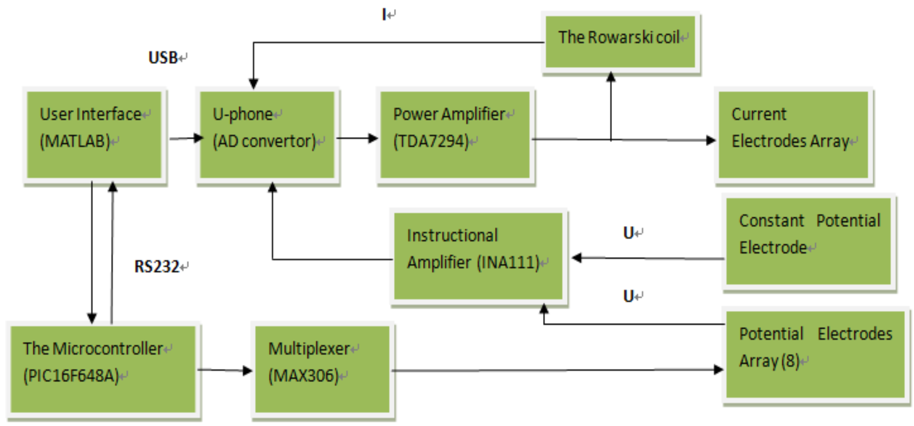

Figure 6. Tree Root Measurement System Hardware Diagram

5. Software Design

The software of the tree root zone measurement system could be divided into two parts including the automatic electrodes changing and the signal processing. The electrodes changing code is written in C and loaded into the microcontroller for communicating with Matlab to cooperate and also control the multiplexer. Signal processing is achieved in the Matlab, it is responsible for sending the driving digital signal to A/D convertor, collecting digital signal from the A/D convertor, and the data analyzing. An user interface is also developed using Matlab for convenience. The interface is shown in Figure 7.

6. Tests and Results

According to the structure of the tree root system, the tree root is mainly made up of two parts, the fine, soft root which is electrical conductive and could be seen as conductor and the think isolated root which is electrical resistive and could be seen as resistor with very large value. A simulation of tree root segment using electronic components is built on the circuit board. After the test on a simulation of the tree root system, the system is applied on a small plant. The result is shown in Figure 8.

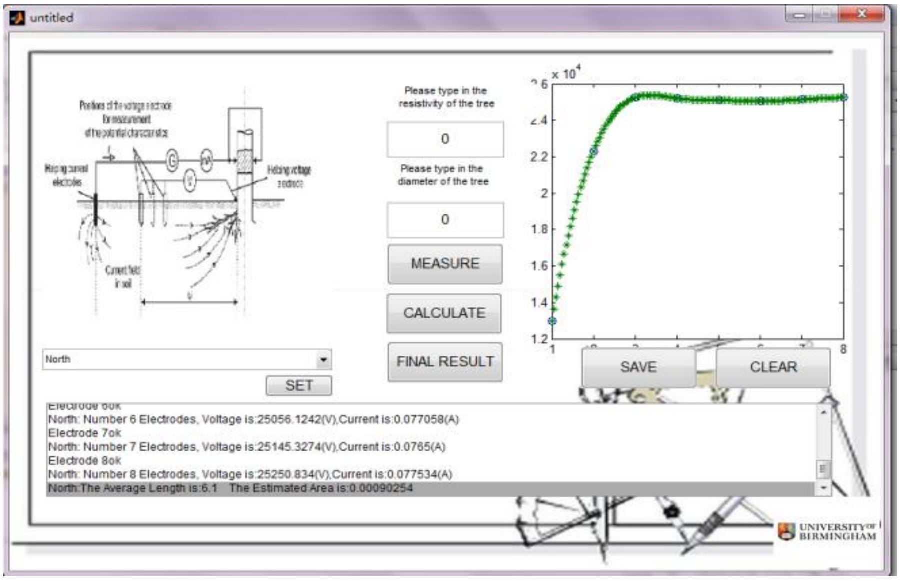

Figure 7. Tree Root Measurement Software

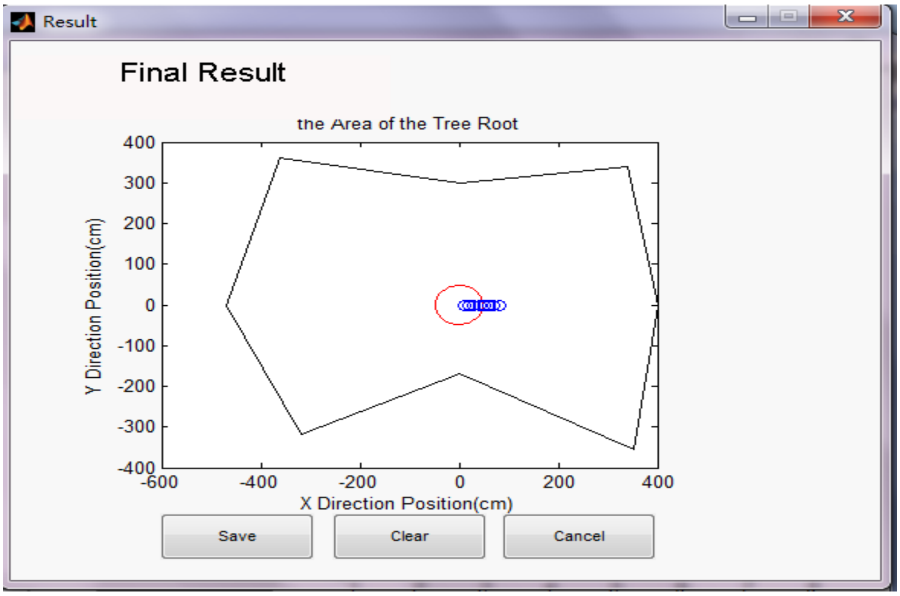

Figure 8. Result of the Simulation Test and Plant Test

7. Conclusion

The structure of the tree root is studied and then the theoretical analyzing method which depends on the fine, soft part of the root is built. The theoretical calculation and result is also given. A tree root zone measurement system including the hardware and the corresponding software is then built which could identify the boundary of the tree root zone by identifying the fine, soft root and calculate the absorption zone. The system is tested in a laboratory built tree root simulation using electronic components and a actual small plant. The test result satisfies the theoretical result. It provides potential to serve as a more efficient, inexpensive and time-saving ways to approximately image the tree root system for some purples when the resolution of the image is not very high.

References

[1] J. M. Reynolds, “an Introduction to Applied and Environmental Geophysics”, New York: Wiley, **(1997)** April.
[2] M. H. Loke, “Electrical Imaging Surveys for Environmental and Engineering Studies”, **(2000)**.
[3] X. Li, G. Zhang and J. Wu, “The Electrical Measurement System Based on Digital Electrodes”, Progress in Geophysics, vol. 24, no. 2, **(2009)**.
[4] L. Aubrecht, Z. Stanek and J. Koller, “Electrical Measurement of the Absorption Surfaces of Tree Roots by the Earth Impedance Method 1. Theory”, Tree Philosophy 26, **(2006)**, pp. 1105-1112,
[5] L. Zhang and H. Wang, “Data Acquisition System of ERT Based DSP and FPGA”, Chinese Journal of Sensors and Actuators, vol. 24, no. 7, **(2011)**.
[6] Yuxi Wang, “High Density Resistivity Characteristics and Application of the Main Device”, Doctor Dissertation, **(2010)**.
[7] R. G. Bearce, and M. A. Mooney, “Electrical resistivity imaging of laboratory soilcrete column geometry”, Journal of Geotechnical and Geoenvironmental Engineering, vol. 142, no. 3, **(2016)** March 1.