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A Review of Application Electrical Resistance Tomography for Rooted Herb Tree Detection

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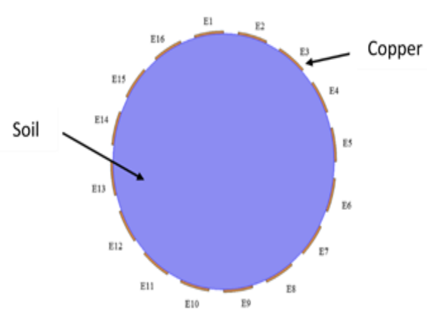
Graphical abstract



Abstract

This paper presents the measurement strategy of Electrical Resistance Tomography (ERT) for a system using underground investigation and comparison with other application such as conducting vessel pipe and concrete. Measurement of electrical strategy commonly used are adjacent strategy, opposite strategy, diagonal strategy and bounding conducting. This paper also discussed in measurement strategy for underground such as the Wenner-alpha configuration, Pole-Dipole array, cross bore-hole ERT and pseudo-section. This paper focuses on the principle and advantages measurement strategy for underground investigation and for other system such as conducting vessel pipe. The soil resistivity testing was described for related with rooted tree detection in soil.

Keywords: Electrical Resistance Tomography (ERT), Underground Detection, Image Processing

1.0 INTRODUCTION

There are many definitions for the word tomography. The word tomography is derived from the Greek word 'Tomo' which means to slice or cutting section and the word 'Graph' mean an image or drawing. In medical states tomography using of radiographic equipment, where any of the methods for making the x-ray of a plane section of a solid object such as the human body. In other word, tomography refers to imaging by sections or sectioning. There are many types of tomography such as Electrical tomography (ET) which is included electrical resistance tomography (ERT), electrical impedance tomography (EIT), electrical capacitance tomography (ECT) and magnetic induction tomography (MIT).

The principle of ERT is reconstructing the resistance distribution and forms an image to reflect the different phase substance distribution in the pipe or vessel. The obtaining of the image is through a certain reconstructing algorithm, which will decide the quality and precision of the image. The tomography process by using the external sensor is to detect the signal from the boundary of the object. The process also involve by taking the measurements around the periphery of the object to confirm or determine what is going on inside it. In the process tomography there are many different imaging methods are practiced such as ERT, EIT, ECT and MIT.

ERT sensor is treated as single, consist of the 16 electrode sensor. The simulation of ERT studied by using simulator: COMSOL Multiphysics, which can give a full overview of the model and access to all functionality. The results were compared with the experimental result. The simulation is based on the mixing materials: water and air, and concrete and steel. Since this is initial studies, it can be any materials to find out what will affect the electrical characteristic of Electrical Resistance Tomography

(ERT). The objectives of this review is to focus on measurement strategy which used by other researchers either applied for vessel pipe or underground investigation. The approaches for measurement by the researcher have own principle and advantages.

The related objective of this paper is to combine the agricultural field and technology of tomography. In this research, the aim is to develop a technology in agriculture field based on engineering and make this system easier and intelligent. The whole process is non-destructive for investigation of the underground. This research implements into rooted herb tree such as *Panax Ginseng*. The process can implemented to investigate for the maturity of this plant without dig the soil. This system also suitable for *Eurycoma Longifolia* also called 'Tongkat Ali'.

There are many research can be done in order to study more about tomography sensors. Make the comparison which software can produce more accurate results when doing the simulation. The simulation can be studied further by using other mixing materials and find the most suitable multiphase materials.

2.0 OVERVIEW OF TOMOGRAPHY PROCESS

There are many methods that related to the tomography's process that mostly related to the medical parts which are positron emission tomography (PET), ultrasonic imaging and magnetic induction tomography (MIT). Based on the review, there are many methods can be used for the process of tomography such as Electrical Resistance Tomography (ERT), Electrical Capacitance Tomography (ECT) and Electrical Impedance Tomography (EIT). A device used in tomography is called a tomograph, while the image produced is a tomogram. The types of tomography are 'hard field' and 'soft field'. Hard Field Tomography means that irrespective of the type of material or medium, the direction of travel of the energy waves from the power source is constant. Instances of Hard Field Tomography are X-ray micro-tomography (XMT), Positron emission tomography (PET) and Magnetic Resonance Imaging (MRI). Electric current is introduced to the medium being imaged and the electric field distribution is defined by the physical, electrical properties of that material, allowing a map of resistance, capacitance or impedance to be restored by a computer to form the tomogram. The nature of soft field is much more complex than hard field, and requires considerably more computer analysis and algorithms to reconstruct the image [1]. Models of Soft Field Tomography are Electrical Resistance Tomography (ERT), Electrical Capacitance Tomography (ECT) and Electrical Impedance Tomography (EIT).

This section describes the studies and research that related to tomography's process and focused on types of measurement strategies for ERT system. From all the methods, this project will be proceeded by using the ERT method.

2.1 Tomography for Industry, Medical and Agriculture Field

Usually, tomography process applications very wide used in medical field. Described by Bown and Record, in the late 1970s, for increasing successful x-ray scanner, the biomedical engineers popularizing the tomographic resistivity measurement technique using circular arrays of electrodes as a low-cost and portable alternative [2, 3]. Based on Rahman *et al.* [4], said for looking at the structure of tissue in the body using X-ray, optical coherence tomography (OCT), Positron Emission Tomography (PET), Magnetic Resonance Imaging (MRI), and ultrasound. X-ray technology makes it possible to see straight through human tissue to check for broken bones, tooth decay, and swallowed objects with ease. Ultrasound has been applied to image human bodies; it is portable, free of radiation risk, and relatively comparatively when compared with other imaging modalities such as MRI and CT.

The industrial sector consists of Optical Coherence Tomography (OCT), Electrical Impedance Tomography (EIT), Electrical Resistance Tomography (ERT), optical Capacitance Tomography (ECT), and Tomography Ultrasonic (UT). Both ultrasound and CAT scans are the medical uses of this technique, but it is also widely used in science and industry [4].

The industry field widely used for connecting pipe application such as to detect and monitor flow through the pipe. Based on Suzanna *et al.*, example industry tomography to investigate the detection of bubble in a metal wall using ERT of 16 electrode system [10]. ERT offers a non-invasive, low cost, nondestructive, no radiation, and visualization measurement manner. ERT has become an accepted measuring technique in the process of engineering applications [24].

The tomography system also applied in agriculture field. Many experiments based on the properties of soil, root, leaves, wood are carried on using tomography method. Related to this approach, root research under natural conditions is very labor intensive and time consuming. The new path for root research can help avoid destructive sampling and allowing an intensive root study with using new high technologies. Based on Rosst *et al*. [25], for soil texture image reconstruction, electrical resistivity tomography is the suitable method. This method is capable to detect stones, tillage effects on soil, soil texture, bulk density and water contents. It is an important part for fertilization of soil checkup.

2.2 Electrical Resistance Tomography

An ERT system comprises a sensing element, a data acquisition system (hardware) and PC with control and information processing software. Tomography process. Electrical Resistance Tomography (ERT) is non-instructive method based upon a reconstruction profile of electrical conductivity inside a medium of interests from measurement made on its boundary [5]. Electrical resistance tomography (ERT) is a specific form of soft-field process tomography technique. As an on-line measurement technique possessing advantages of visualization, non-invasion, low cost, and non-radiation, ERT has become an accepted measuring technique in process of engineering applications [6]. The typical of ERT structure is composed of three basic parts that are sensors, signal conditioning, data acquisition system (DAS) and the image reconstruction system [7]. The ERT technique must have continuous electrical contact with the conductive liquid inside the vessel. The conductivity of the sensor electrodes must have higher conductivity properties compared to the liquid conductivity. The data acquisition system performs a series of function which are waveform generation and synchronization.

The objective of ERT is to achieve cross section images through a set of boundary sensor array to obtain the real-time distribution of electric materials with a contrast in conductivity. Figure 1 shows the basic tomography system in illustration. The research configures with using 8 electrodes and put into sand and around root plant for underground investigation.

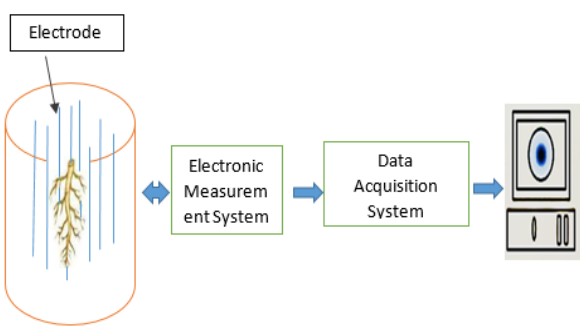


Figure 1 The process of tomography for root detection

2.3 Tomography on Geophysical or Underground Investigation

Ground is a part of surface in the earth that consists of mineral and organic materials. Ground is also very importance for all life on the earth this is because the land is capable of supporting life such as plants where the land that provides is importance. In electrical designing, ground or earth is the reference point in an electric circuit from which the voltages be measured and a typical return way for the electric current or a physically associated with the earth. The earth serves as a sensibly steady potential reference against which alternate possibilities can be measured is with the end goal of estimations.

The utilization of ground or earth is usually in the electrical and gadget applications that the circuits in the versatile electronic gadgets, for example, in the cell and the media players and in addition the circuits in vehicles. As the regular return way to present from numerous distinctive segments in the circuit, typically a huge conductor is joined to one side of the force supply, for example, the ground plane.

Usually for detection of underground investigation most researchers apply the ERT system to get the imaging cross section. Based on Josep Jordana *et al.* [8] for Leakage Detection in Buried Pipes by Electrical Resistance Imaging, the objective using ERT are considering subsurface resistivity measurements to detect leakage from buried pipes without soil drilling and as alternative to soil studies based on apparent resistivity curves. The research of application of Electrical Resistivity Tomography for Detecting Root Biomass in Coffee Trees by Carlos Mauricio Paglis [9] using ERT for detects root coffee. The result shows that the electrical resistivity tomography can contribute to root biomass studies in coffee plants.

3.0 DATA COLLECTION STRATEGIES

Some of the common data collection strategies suited to a single-current source/sink-drive stage includes: the adjacent strategy; the opposite strategy; the diagonal strategy and the conducting boundary strategy.

3.1 Adjacent Strategy

The common measurement strategy that researcher use is adjacent strategy also called Neighbouring Method [10]. The principle of adjacent strategy is injection of current between an adjacent pair of electrodes. In the neighboring method [Brown and Segar, 1987], the current is applied through neighboring electrodes and the voltage measured successively from all other adjacent electrode pairs. All current electrode pairs will be used sequentially, producing 16 current injection patterns when 16 electrodes are used [11]. The total number of independent measurement given by following equation:

$$M=\frac{N(N-3)}{2} \tag{1}$$

Figure 2 shows the measurement strategy for adjacent method and the color of black represent the injection current and the red is measurement of voltage. For example e_2 and e_3 for injection current and measurement voltage electrode pair for e_4 and e_5, e_5 and e_6, e_6 and $e_7 \ldots e_{16}$ and e_1. The advantages of adjacent method are quick in terms of image reconstruction, undemanding of computational memory, and high sensitivity at periphery but low sensitivity at the middle compare with other methods.

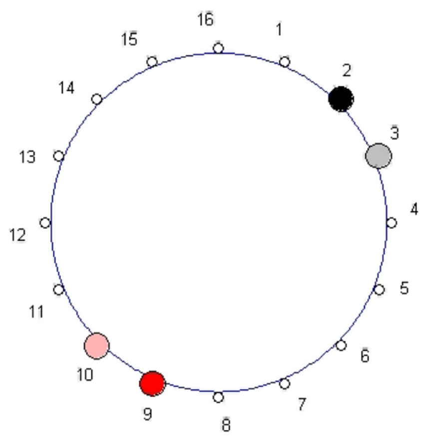


Figure 2 The adjacent measurement strategy [18]

3.2 Opposite Strategy

In opposite method, the current is injected through two diametrically opposed electrodes. This evidently should produce more field strength in the deeper regions of the medium. Compared with the adjacent strategy, the opposite strategy is less sensitive to conductivity changes at the boundary since most of the current flows through the central part of the region. Hua [13] noted that the opposite strategy yields a relatively good distinguishability due to the even distribution of currents. Breckon and Pidcock [14] showed that, for the opposite strategy, the number of independent measurement M is given by following equation:

$$M = 8X13= 104. \quad (2)$$

The value of 8 represent the current and 13 represents the voltage. The value of independent measurement is 104 by using 16 electrodes. The advantage of opposite strategy is less sensitive to conductivity change (as in adjacent strategy) as current flows through the center point of the cross-section. This gives rise to even distribution of currents, leading to a good image characterization [14]. A relatively good distinguishability due to the even distribution of current.

Figure 3 shows the measurement strategy for opposite method. The voltage reference is the electrode adjacent to the current-injecting electrode. Then the pair of current-injecting electrodes, the voltage is measured with respect to the reference at all the electrodes except the current-injecting ones. The next data set is obtained by switching the current to the next pair of opposite electrodes in the clockwise direction. The color of black represents the injection current for e_1 and e_9. The color of red represents the measurement electrode pair and e_2 as a reference.

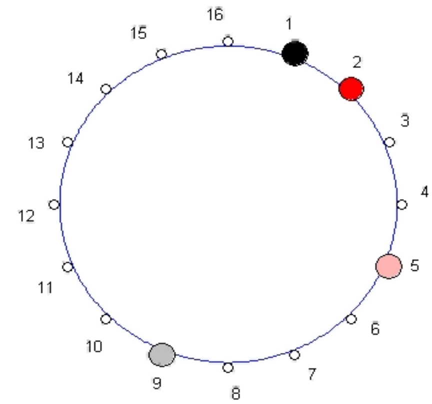


Figure 3 The opposite measurement strategy [18]

The diagonal strategy is also known as the cross method. The cross method aims to produce more homogeneous fields than the neighboring method. This is obtained by using more distant electrodes instead of the adjacent ones [13]. The outcome, with respect to the adjacent strategy, is a more uniform current distribution in the region being imaged. The number of tetrapolar independent measurements by the following equation:

$$M = 7X13= 91 \quad (3)$$

The value of 7 represents the value of current and 13 represent the value of voltage. The independent measurement is 91 by using 16 electrodes. The advantage of diagonal strategy does not yield a high sensitivity in the periphery compared to the adjacent method. However, it has better matrix conditioning and sensitivity over the entire region and is not as sensitive to measurement error. Thus, produces a better quality image [15].

3.3 Diagonal Strategy

Figure 4 shows the measurement strategy for diagonal method and the process how to inject current and measure the voltage. For example e_{16} fixed as a current reference, e1 as a voltage reference current applied with electrodes 2, 4, 6, 8…14. With electrode injection current pair, the voltage measured for all electrodes except an electrode injection current pair respect with e_2.

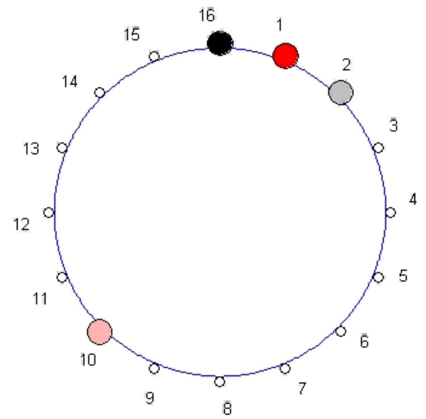


Figure 4 The diagonal measurement strategy [18]

3.4 Conducting Boundary Strategy

The conducting boundary strategy usually uses for process vessels and pipelines with electrically conducting boundaries. Each electrode acting sequentially as a current source and voltage measurements is references to the same earth potential. The conducting boundary strategy employs only two electrodes. The conducting boundary method has a significantly lower common-mode voltage component than adjacent method. Wang [19] noted that it to be 800 times smaller for the conducting boundary method.

Figure 5 shows the conducting boundary measurement. For example inject current e_1 and measured voltage e_7. Voltage measurements are referenced to the same earth potential. The conducting boundary method is suitable for conducting a vessel than adjacent strategy.

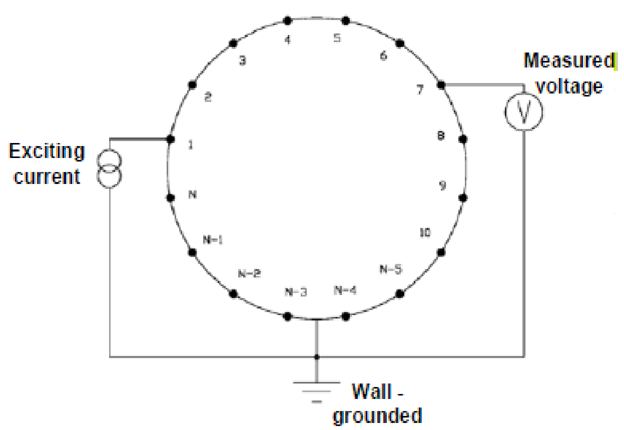


Figure 5 The conducting boundary measurement strategy [11]

3.5 Strategies for Underground Investigation

Some researcher used other strategies for underground investigation, such as Wenner Alpha configuration [20], pole-dipole configuration [9], cross bore-hole ERT [21] and pseudo-section [22]. Based on Christos and George [23] for the analysis of different geophysical methods in the detection of an underground opening at a controlled test site, the Pole-Dipole array produces a model with good lateral resolution, great depth, and wide coverage. If both forward and reversed measurements using the Pole-Dipole array is combined, the inversion of these data provides improved image of the underground.

Figure 6 shows the Wenner-alpha configuration. C is represent of current electrode and P is represented potential electrode. The distance of electrode is a, also called electrode separation.

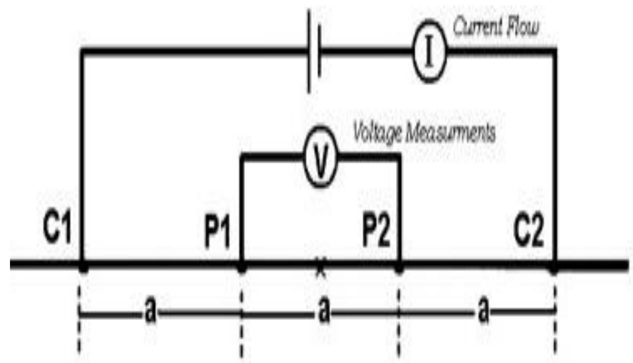


Figure 6 Layout of Wenner-alpha configuration [20]

4.0 SOIL RESISTIVITY TESTING

To determine the conductivity of the ground must through with soil resistivity testing process of measuring a volume of soil. The result for soil resistivity determine in ohmmeter or ohm-centimeter. Soil resistivity testing is the single most decisive element in electrical grounding design. The basis of all grounding design when implemented good soil and they developed from accurate soil resistivity testing.

Usually, a method to measure the resistivity of soil most used by researchers is Wenner 4-point as shown in Figure 6. Other methods also used, for example the General and Schlumberger methods, but other methods are infrequently used for grounding design applications and vary only slightly in how the probes are spaced when compared to the Wenner Method. Characteristic for measurement resistance between soil and electrode are humidity of the soil (more water makes the soil conduct electricity more easily (less resistance), while dry soil conducts electricity poorly (more resistance). The material of the electrode also gives effect for resistivity soil because the good conductor material, good for resistivity soil.

5.0 FINITE ELEMENT ANALYSIS AND RECONSTRUCTION FOR ERT

Image reconstruction is mean to merge the information received from sensors that captured images of an object measured at different angles and views. The tomographic images are derived using a back projection algorithm. The tomographic images are derived using a back projection algorithm. In order to derive this algorithm which results the solution to the inverse problem, the forward problem must be solved first. The route of electric currents in ERT are not straight lines. Current diffuses all over the target, and the current distribution in the material depends on the internal conductivity distribution σ = σ (r) [26]. The forward model which links up to the dependency between conductivity distributions and boundary voltages need to be solved first before to solve the opposite problem. Since the ERT model is nonlinear and difficult to be solved analytically, the finite element method (FEM) is preferable to solve for the forward model. From the solution, the data are interpolated to generate the sensitivity distribution and then be used to solve the inverse problem later. Finite element method using suitable software recommended to solve for the forward model.

Forward model will be applied later to solve the inverse problem which is the reconstruction problem in ERT. The so far the most accurate model for ERT measurements is the complete electrode model introduced by Cheng *et al.* [27]. The complete electrode model consist of the following partial differential equation and the boundary conditions

$$\nabla.(\sigma\nabla u)=0, r\in\Omega \tag{4}$$

$$\int_{el}\sigma\frac{\partial u}{\partial n}dS = I_{l,} r\in e_l . l=1,....,L \tag{5}$$

$$\sigma\frac{\partial u}{\partial n}=0, r\in\partial\Omega \setminus \mathrm{U}_{l-1}^{L} e_l \tag{6}$$

$$u+z_l\sigma\frac{\partial u}{\partial n}=U_l r\in e_l l=1,.....,L \tag{7}$$

where;
Ω = computational domain
σ = σ(r) = conductivity distribution
u = u (r) = electric potential inside Ω
U_l = potential on l th electrode
I_l = current on l th electrode
z_l = contact impedance between the l th electrode and the object
n = outward unit normal

In addition, the Kirchoff's current Law

$$\sum_{l=1}^{l} I_1 = 0 \tag{8}$$

Must be carried through, and the potential reference level has to be set, for instance by writing

$$\sum_{l=1}^{l} U_1 = 0 \tag{9}$$

The solution of the ERT forward problem is by computing electrode potential U_l given the conductivity distribution and the electrode current I_l is obtained by solving the partial differential equation (4) with the condition (5)-(9). The system (4)-(9) has a unique solution which can be approximated by using finite element method (FEM) [28]. The FE approximation of the model results the following form

$$V = R(\sigma, z)+\mathrm{v} \tag{10}$$

where;
V = voltage observations (potential on l th electrode, U_l)
$R(\sigma, \mathrm{z})$ = mapping from the conductivity distribution σ and the contact impedance z to the electrode voltages
v = measurement noise vector

6.0 CONCLUSION

This paper has described different methods used to how arrange the measurement strategy by using electrode arrangement. The principle, advantage and disadvantages for data collection strategy has described. This paper has presented an overview of the important aspects of an electrical resistance tomography system for use in process application. A low cost and fast response ERT system for underground investigation will be developed and the system will able to measure the maturity of the rooted herb plant.

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