SOIL MOISTURE DETECTION USING
ELECTRICAL CAPACITANCE TOMOGRAPHY (ECT) SENSOR

by

Nurzharina Binti Abd.Karim

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical and Electronic Engineering)

MAY 2011

Universiti Teknologi PETRONAS
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CERTIFICATION OF APPROVAL

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TRONOH, PERAK
MAY 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

NURZHARINA BINTI ABD. KARIM

ABSTRACT

This report consists of five chapters which are introduction, literature review, methodology, results and discussions, and conclusion and recommendations. The introduction portion explains about the background of study of the project, problem statement, project objectives and scope of the study. The objectives of this project are to design an Electrical Capacitance Tomography (ECT) sensor for soil moisture detection, calibration measurement for lower and higher permittivity material, and conducting online measurement to measure the percentage of moisture content in soil. The literature review describes the research about the project topic such as ECT technique and soil moisture measurement. ECT is a measurement technique used to obtain the visualization and measurement of a permittivity distribution in a cross section using multi-electrode capacitance sensor. The methodology part contains research methodology process flow, project activities with key milestone table as the attachment, tools required to run the project, and experimental procedure to conduct the experiment. The results and discussion contains the fabrication result of the ECT sensor, low calibration results, online measurement results, and discussion about the results obtained. The preliminary result shows that there is a positive correlation with increasing moisture percentage in soil. The conclusion consists of overall conclusion regarding the report. For future improvement, the experimental procedure will be improved by conducting a test on different types of soil. A simple wireless control system to control the irrigation event by detecting and analyzing the percentage of moisture in soil is recommended.

ACKNOWLEDGEMENT

First and foremost, I would like to thank Allah the Almighty who has given me strength and blessings to complete my Final Year Project. The utmost gratitude goes to my supervisor, Ir Dr Idris Bin Ismail for having his time to guide and assist me in my Final Year Project. His guidance, support and encouragement have kept the work on the right track with continually motivation. I would also like to give appreciation to Mrs. Areeba Shafquet who has been helping me through many challenges during this project. Moreover, my gratitude goes to all lecturers and lab technologists who had given their help, time, guidance and advice throughout this project. Special thanks to lab technologist Mr. Azhar and Mrs. Siti Hawa who assisted me in the laboratory. I would like to use this opportunity to express my deepest appreciation to everyone who has contributed towards this project directly or indirectly. Last but not least, not forgetting my family members and fellow friends who had gave me moral support and motivation.

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LIST OF ABBREVIATIONS

Electrical Capacitance Tomography . . . . . ECT

Electrical Resistance Tomography . . . . . ERT

Industrial Tomography System . . . . . ITS

Multi-Model Tomography System . . . . . MMTS

Polyvinyl chloride . . . . PVC

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The background of study of this project covers the study of Electrical Capacitance Tomography (ECT) and soil moisture distribution measurement by using ECT sensor. The basic idea of this project is to design a sensor that uses ECT technique in order to measure and capture the image of moisture distribution in soil. Soil is used as the measurement medium as it has pore space that can hold water and air in it. Therefore, as the water fills in the pore space, the changes in the percentage of soil moisture can be determined by indicating the amount of water content in soil.

1.1.1 *ECT Sensor*

ECT has been developed since 1980s for visualization and measurement of a permittivity distribution in cross section using a multi-electrode capacitance sensor [25]. ECT is one of the measuring techniques derived from the tomography imaging. Physical arrangement of a basic ECT system consists of three major parts; capacitance sensor, data acquisition unit and a control computer [17]. In addition, Figure 1 shows the project environment where the sensor is connected to the data acquisition unit through high-speed serial links. The high speed USB cable connects the data acquisition unit to the control computer. Data from the acquisition unit is then sent out to a control computer for data storage, processing and output display.

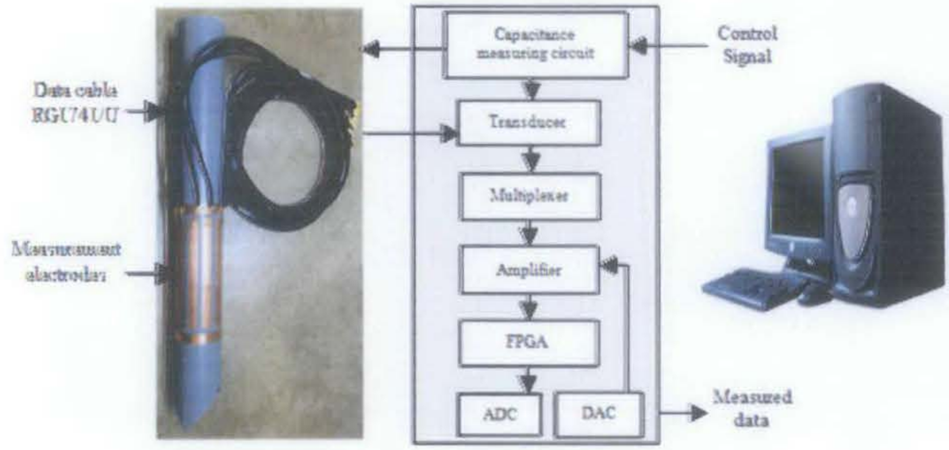


Figure 1: Tomography system

1.1.2 *Soil Moisture*

The ECT sensor measures the distribution of permittivity of the soil inside the insulating pipe and captures the image reconstruction and measurement data. The soil moisture measurement is based on the concept of the dielectric constant in a dry material consisting soil particles and air is relatively small (1.5 to 4) whereas the dielectric water constant is larger (80 at room temperature). The small amounts of water in soil cause the dielectric constant of the resultant soil-water-air mixture to exhibit a composite dielectric constant that can be related to the soil moisture content through a simple calibration procedure [18].

The project will focus on monitoring the irrigation system by using the ECT sensor in measuring the percentage of moisture in the soil. This is because continuous monitoring of soil moisture content may facilitate optimal irrigation scheduling. In order to determine the maximum optimal irrigation management, a system is designed to monitor the changes in soil moisture percentage during the irrigation process, thus control the amount of water applied to the soil. Actually, the estimation of soil water content is important in agriculture. Water content impacts crop growth directly and also influences the fate of agriculture chemicals applied to soil [23].

1.2 Problem Statement

In agriculture industries, irrigation system is used to apply water to soil and assists the growing of agricultural crops, maintenance of landscapes, and revegetation of disturbed soils in dry areas as well as during the period of inadequate rainfall. A common issue with irrigation system is determining the percentage of moisture content in soil. For example, if the irrigation system is applied to an area that has inadequate or adequate rainfall, the soil may have unbalance percentage of moisture content at that period of time which is not suitable for the plant growth.

1.2.1 *Problem Identification*

The image of percentage of moisture distribution is important in order to identify the percentage of moisture in soil. In order to overcome the problem, the capacitance technique is used to sense the moisture in soil thus controlling the irrigation system in a better way. Before any modelling or design can be made, the needs of understanding in ECT and soil properties are important. Besides, having to understand the characteristic of ECT sensor and learning the method used in determining the data acquisition and analysis are also needed for the completion.

1.2.2 *Significant of Project*

The idea of the project is basically to come up with a sensor design using ECT for soil moisture detection that can be applied in agriculture irrigation system in order to ensure that the soil has proper percentage of moisture. By using Linear Back Propagation (LBP), the image of moisture distribution in soil can be analyzed. Other than that the sampling data is analyze by using MS Excel.

1.3 Objectives

The main objective of this project is to design a sensor for soil moisture detection using ECT technique. The details of the objective are as follows:

i. Sensor design - which consists of hardware and software. The hardware portion is the ECT sensor while the software is the application used to design the sensor. Several considerations have to be made in terms of measurement electrodes, shielding, and material used to build the sensor.

ii. Calibration - includes high and low calibration for lower and higher permittivity material. Oven-drying method will be used as a testing standard to determine moisture percentage in soil.

iii. Online measurement – measure percentage of moisture distribution in soil by using moisture distribution image pixel in ECT and oven-drying method.

iv. Empirical model analysis – empirical models by *Topp et al.* 1980 and refractive index model are example of empirical models that is used in analyzing the dielectric constant and volumetric water content of the soil.

1.4 Scope of Study

The scope of study will evolve on designing ECT sensor by understanding the concept of ECT. In order to implement the ECT sensor to the soil, the basic knowledge of soil properties must be emphasis. The measurement of the soil moisture involves the ECT sensor and the software for testing, capturing, calibrating, and analyzing the data acquisition from the measurement. Industrial Tomography System (ITS) Tomography Toolsuite Software is useful for the project in obtaining accurate calculations and results.

1.4.1 *Relevancy of the Project*

This project is relevant to the study of Instrumentation and Control System as it focuses on the design capacitance sensor and control unit of the ECT which deals with electronic design. Even though the technology of ECT has already existed, but the measurement in soil moisture can be further studied to improve the performance of the design and the control unit of the ECT.

1.4.2 *Feasibility of the project within the scope and time frame*

The project scope and time frame is referred to the project key milestone and Gantt chart. The project will be conducted starting with the collection of related materials such books, journals and technical papers specifically on ECT application and soil measurement. Research will be done from time to time to get a better understanding on the subject. The sensor design and fabrication has been done and high and low calibration of the sensor has been conducted by calibrating the dry sand for low calibration and saturated sand for high calibration. The online measurement has been conducted and the data is recorded. In order to compare the experimental data obtained from ECT measurement, another method to determine moisture content in soil is conducted that is oven-drying method.

CHAPTER 2

LITERATURE REVIEW

2.1 ECT

In ECT the changes in inter-electrode capacitance due to the change in concentration and/or distribution of dielectric materials in the region are measured, and a cross-sectional image representing the permittivity distribution inside a pipe or vessel is reconstructed [19]. ECT measures the capacitance between electrode pairs, captures and converts the measurement data into an image permittivity distribution through data acquisition system.

2.1.1 *The Differences between ECT and ERT*

Basically, ECT and Electrical Resistance Tomography (ERT) have been developed separately as non-intrusive and/or non-invasive imaging techniques in the past [27]. ECT can be used to visualise permittivity distributions while ERT is used to visualise conductivity distributions [27]. Therefore, the ECT mode can be used to measure the dielectric component and ERT mode can be used to measure the conductive component. Both techniques that are stated before have their own advantages and disadvantages.

The differences and advantages, and disadvantages of ECT and ERT are shown in Table 1. The ERT measurement precision sometimes may be poor. Generally, in phase-flow, it has some strength compared to other techniques which are ERT can provides two or three dimensional information on two-phase flow and phase distribution can be constructed various times. The advantages of

ECT over other industrial tomography modalities are no radiation, fast imaging speed, non-intrusive and non-invasive, robust, withstanding high temperature and high pressure and of low cost [18].

Table 1: Differences between ECT and ERT

ECT	ERT
Visualise permittivity distributions.	Visualise conductivity distributions.
Measure the dielectric component such as air, oil, or sand.	Measure the conductive component such as water acids bases and ionic solutions.
The advantages are no radiation, rapid response, low cost, non-intrusive and non-invasive.	Provide 2D and 3D flow, phase distribution can be constructed.
The disadvantage is issue of stray capacitance.	Low measurement precision but it is feasible to find precise method.

2.1.2 *The Differences between ECT and Other Electromagnetic Techniques*

Typically, Time-domain reflectometry (TDR) method, frequency-domain reflectometry (FDR) method, amplitude-domain reflectometry (ADR) method and capacitive method are the current methods available for the electrical measurements of the dielectric constant [14]. For example, TDR instruments use measured pulse travel times to determine the apparent soil dielectric permittivity [16]. Some of the researchers found that the capacitance probe method was independent of soil type within wide ranges of soil moisture levels [2]. However, these methods do not determine the image distribution of the moisture in the soil. In ECT, the image distribution of permittivity material can be seen in the form of image pixel depending on the scale of the permittivity material from lowest to highest value.

2.2 ECT Sensor Design

There are several matters that are considered in ECT sensor design which are number of electrodes, external or internal electrodes, driven guard electrodes, and earthed screen. The lists are as follows:

i. Technique or concept that is considered in designing the sensor.
ii. Number of electrodes.
iii. Length of electrodes.
iv. External and internal electrodes.
v. Earthed screens.
vi. Capacitance and Maxwell models for permittivity and water content.
vii. Normalize capacitance.
viii. Image reconstruction.

2.2.1 *Capacitance concept*

Capacitance is the main component that harnesses electric charge which has essentially a pair of conductors containing moveable electric charge separated by a dielectric or insulator. A capacitor is formed when any two conducting bodies (regardless of the shapes and sizes) separated by an insulating medium [9]. Capacitance can be defined as the magnitude of charges, Q on both electrodes divided by the potential difference between electrodes, V. The voltage supply will transport charge from one plate to the other until the voltage produced by the charge build up is equal to the voltage supply. Capacitance is typified by a parallel plate arrangement and is defines in terms of charge storage in equation (1):

$$C = Q/V \qquad \text{eq. (1)}$$

where,

Q = magnitude of charge stored on each plate

V = voltage applied to the plates

2.2.2 *Number of Electrodes*

The first step to design an ECT is deciding the number of electrodes on the sensor. With small number of electrodes, the expected benefits are a smaller number of data acquisition channels are required, a faster data acquisition rate as the number of capacitance measurement is reduced, and the length of electrodes may be reduced due to the increased cover angle of the electrodes resulting in increased inter-electrode capacitance. However, with a small number of electrodes, the number of independent capacitance measurements is small and therefore a good image can not be expected [25].

The basic method is to surround the vessel or pipe with a set of electrodes (metal plates) and take capacitance measurements between each unique pair of electrodes [7]. The number of independent capacitance measurements can be calculated by N (N-1)/2, where N is the number of electrodes. Based on the number of independent capacitance measurements equation, there are 66 independent capacitance measurements for 12 electrodes ECT sensor. Example of twelve electrodes arrangement is shown in Figure 2.

Table 2: The relationship between number of electrodes and number of independent measurements

No. of electrodes	No. of independent measurement	Typical speed (frames s^{-1})	Application example	References
6	15	400	Visualizing combustion flame in an engine cylinder with to achieve 36000 frames s^{-1}	Waterfall *et al.* (1996)
8	28	200	Imaging a wet gas separator.	Yang *et al.* (2004)
12	66	100	Measuring gas-oil-water three-component flows.	Yang *et al.* (1995)
16	120	50	Imaging the nylon polymerization process.	Dyakowski *et al.* (1999)

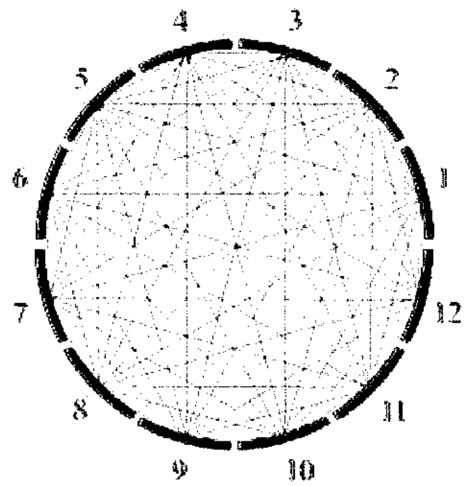


Figure 2: 12 electrodes arrangement

2.2.3 *Length of Electrodes*

Although smaller and larger ECT was attempted, the diameter of an ECT sensor is usually between 1 and 4 inches (between ~2.5cm and ~10cm) [25]. Typically, the length of electrodes is larger than the diameter of the insulating pipe so that a serious fringe effect at both end axial can be avoided.

2.2.4 *External and Internal Electrodes*

The external or internal electrodes are mounted in the insulating frame or outside the insulating frame. The electrode configuration for internal and external arrangements are developed depending to the application requirements. The wall has negative effect on the measurement of the internal capacitance because the wall capacitance effectively in series with the internal capacitance [24]. The thinner wall gives better sensor performance in order to resolve the internal capacitance measurement. It has been suggested by some researches to use driven guard electrodes in ECT sensors, attempting to enable shorter measurement electrodes to be used [25].

2.2.5 *Earthed Screen*

The function of the earthed screen is to prevent interferences between the sensor's applied signal and any devices present near the capacitance sensor. The electrodes are used to initiate the charge and detect capacitance between two electrodes. The insulation guard function is to reduce stray capacitance between back surfaces of adjacent electrodes. There are three type of earthed screens may be used in an ECT sensor which are an outer screen, two axial end screens, and radial screens. It is crucial to use an earthed outer screen to prevent interference of external noise [25]. It is common to use two earthed axial end screens at both ends of measurement electrodes which can reduce external noise to some extent [5]. The standing capacitance between adjacent electrode pairs can be reduced by using earthed radial screen.

2.2.6 *Parallel and Maxwell Models for Permittivity and Water Content Measurement*

There are several models to relate permittivity and water content such as parallel, series, and Maxwell model. The selection of the model is important to ensure that calculation of water content measurement and the permittivity can be obtained correctly. The capacitance of an ideal parallel-plate capacitor can be calculated if the space between two plates is completely filled with a single dielectric material:

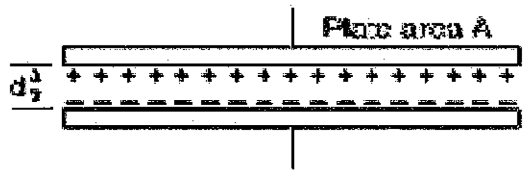


Figure 3: Parallel plate capacitance

The capacitance of a parallel-plate capacitor constructed of two parallel plates both of area, a separated by a distance d is approximately equal to equation (2):

$$C = \frac{\varepsilon_r \varepsilon_o A}{d} \qquad \text{eq. (2)}$$

where,

C = the capacitance in farads, F

A = the area of overlap of the two plates measured in square metres

ε_r = the relative static permittivity of the material between the plates

ε_0 = the permittivity of free space where $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m

d = the separation between the plates, measured in metres.

It was found that the Maxwell model is in between the parallel and series models (Refer to Table 3) [26]. Table 3 shows that basically in Maxwell model the water is evenly distributed in the measurement area, while for series model the water exists in layer form and for parallel model the water is in a column form. The Maxwell equation is as equation (3):

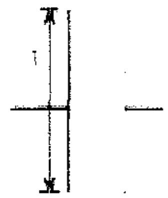
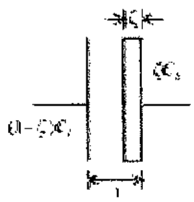
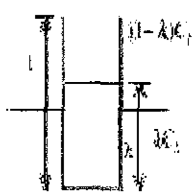
$$\varphi_{Maxwell} = \frac{(\varepsilon_2 + 2)(\varepsilon_r - 1)}{(\varepsilon_2 - 1)(\varepsilon_r + 2)} \qquad \text{eq. (3)}$$

where,

ε_r = the permittivity of the measured material

ε_2 = the permittivity of water

Table 3: Models to relate permittivity and volume of water [26]

Model	Basis	Permittivity calculation	Water volume calculation
Maxwell 	Water (permittivity ε_2) is evenly distributed. Air space permittivity is taken as 1.	$\varepsilon_r = \frac{\varepsilon_2 + 2 + 2\phi(\varepsilon_2 - 1)}{\varepsilon_2 + 2 - \phi(\varepsilon_2 - 1)}$	$\phi = \frac{(\varepsilon_2 + 2)(\varepsilon_r - 1)}{(\varepsilon_2 - 1)(\varepsilon_r + 2)}$
Series 	Water (permittivity ε_2) exists in layer form. Air space permittivity is taken as 1.	$\varepsilon_r = \frac{\varepsilon_2}{\varepsilon_2 - \zeta(\varepsilon_2 - 1)}$	$\zeta = \frac{\varepsilon_2(\varepsilon_r - 1)}{(\varepsilon_2 - 1)\varepsilon_r}$
Parallel 	Water (permittivity ε_2) in a column form. Air space permittivity is taken as 1.	$\varepsilon_r = 1 + \lambda(\varepsilon_2 - 1)$	$\lambda = \frac{\varepsilon_r - 1}{\varepsilon_2 - 1}$

2.2.7 *Normalize Capacitance*

There are two types of measurement is ECT which are calibration and online measurement. The calibration measurement in lower and higher permittivity material gives lower and higher capacitance (C_l and C_h) values respectively while online measurement gives measured capacitance value, C_m. All subsequent measured capacitance values C_m are then normalized to have values C_n between "0" (when the sensor is fully filled with the lower permittivity material) and "1" (when fully filled with higher permittivity material) according to the equation (4) [26]:

$$C_n = \frac{C_m - C_l}{C_h - C_l} \qquad \text{eq. (4)}$$

2.2.8 *Image Reconstruction*

Image of permittivity distribution in 12 electrodes ECT sensor with 66 independent measurements is projected onto a (32x32) square pixel grid. On a (32x32) square pixel grid there are 1024 pixels, but only 812 pixels are needed to construct the cross-sectional image of the vessel [21]. With 812 pixels, there are remaining pixels that are not being used because they are located outside the measurement area. The color scale is used from blue to red that is "0" to "1" to indicate the range of the lower permittivity material to higher permittivity material. In ECT, the measuring capacitance between two electrodes can be expressed by following integral equation (5) [13]:

$$C = \iint_D G(x,y).S(x,y,G(x,y))dxdy \qquad \text{eq. (5)}$$

One of the most commonly used reconstruction algorithm for image reconstruction in ECT system is the LBP because it is the simplest and fastest system for image reconstruction process. The LBP has been implemented to reconstruct images for ECT sensor using 12 electrodes and transducer-based multiprocessor system [3]. With LBP, the permittivity distribution in ECT can be determined. The product of G is multiplication of the transpose of the transducer sensitivity matrix with the normalized capacitance matrix. The relationship can be seen in linear normalized form as in equation (6) [13]:

$$C = SG \qquad \text{eq. (6)}$$

where,

C = the normalized capacitance matrix

S = the transducer sensitivity matrix which contains the set of sensitivity matrices for each electrode pairs

G = the normalized permittivity

2.3 Soil Moisture Measurement

Continuous monitoring of soil moisture content within and below the rooting zone can facilitate optimal irrigation scheduling aimed at minimizing both the effects of water stress on the plants, and also leaching of water below the root zone which can have adverse environmental effects [1]. In estimating the soil water content in agriculture, there are three methods are available which are gravimetric techniques, nuclear techniques and electromagnetic techniques. From those techniques, electromagnetic techniques have become popular because they facilitate a rapid, safe, non-destructive, and easily automated estimation of soil water content [23].

The dielectric constant of a medium depends upon the polarization of its molecules in the electric field. The dielectric constant of water (80) is large compared to the soil matrix (<10) or air (1), a change in water content will strongly influence the dielectric constant of growing medium that is soil-water-air mixture. The relationship between the change in water content and the dielectric constant of the medium depends upon soil type and the frequency range of the measuring apparatus [1]. Besides, some of the researches found that the capacitance probe method was independent of soil type within wide ranges of soil moisture levels [2].

The terminology of moisture content stated in ASTM D4643-08 is the ratio, expressed as percentage, of the mass of "pore" or "free" water in a given mass of soil to the mass of the solid particles [22]. Soil moisture content impacts crop growth directly and also influences the fate of agriculture chemicals applied to soil [23]. One of the key components in managing irrigation scheduling is by determining the moisture content in soil. Zazueta and Xin (1994) reported that soil moisture content may be determined via its effect on dielectric constant by measuring the capacitance between electrode pairs implanted in the soil [8]. The soil physical condition plays an important role in soil moisture determination as well as the ability of the soil to hold ware and the flow rate of water through soil particle and pores space. Other than that, the hydrologic properties of soil play an important role in a crop's ability to transpire water with their root systems [4]. The air and water fill in the pore space in the soil, thus the dielectric constant of the soil-water-air mixture can be measured. Unsaturated soil is composed of solid particles, organic material and pores. The pore space contains root, air and water.

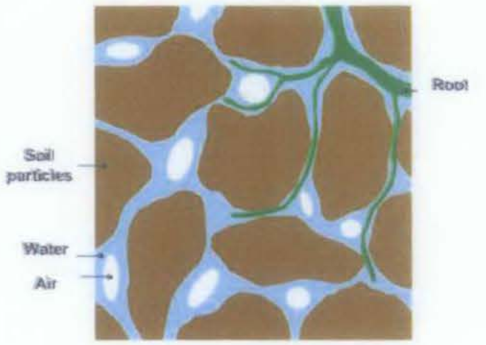


Figure 4: The pore of soil that contains water, air, soil particles and root

2.3.1 *Soil Physical Condition Measurement*

The amount of water can be expressed as a proportion by mass of the dry solid particles which is known as moisture content. The moisture content in soil can be analysed by knowing the soil physical conditions. The soil's bulk density, D_b is the ratio of the mass of dry soil to the volume of soil [20]. Particle density, D_p involves measuring the weight of dry soil and the volumetric soil particle that is only solid and no pore space. From both bulk density and particle density values, the soil porosity can be calculated by using equation (7) [6] [20]:

$$Soil\ porosity = 1 - \frac{D_b}{D_p} \qquad \text{eq. (7)}$$

Gravimetric water content, θ_m determines the amount of water with a given mass of soil. It is calculated by dividing the weight of water by the weight of dry soil. The expression of water content in terms of volume of water per volume of soil can be determined as volumetric water content, θ_v using equation (8) [6][20]:

$$\theta_v = D_b \times \theta_m \qquad \text{eq. (8)}$$

Table 4 lists the guidance to identify the moisture content in different moisture condition by identifying the texture of the soil.

Table 4: Soil Texture Identification

	Texture			
	Coarse (sand, loamy sand)	**Moderately coarse (sandy or silt loam)**	**Medium (loam, clay loam, silty clay loam, silt, sandy clay)**	**Fine (clay, silty clay, light clay)**
At field capacity	60-100	100-150	150-200	200-250
	mm available moisture per meter of soil			
	Soil Moisture Content			
75-100% available moisture	Tends to stick together slightly	Forms weak ball, break easily and will not stick	Forms a ball and is very pliable, slicks readily if relatively high in clay	Easily forms a ribbon between fingers and slick
50-75% available moisture	Appears to be dry and will not form a ball under pressure	Tends to ball under pressure but seldom holds together	Forms a ball and slicks with pressure	Form a ball, ribbons out between thumb and forefinger
25-50% available moisture	Appears to be dry	Appears to be dry	Crumbly but forms a ball	Form a ball under pressure
0-15% available moisture	Dry, loose single-grained and flows through fingers	Dry, loose and flows through fingers	Powdery, dry but easily broken down into powder	Looks moist but will not quite form a ball

Source: Irrigation Practice and Water Management 1 Rev. 1 FAO, 1984

2.3.2 *Dielectric Measurement*

The relationship between apparent soil permittivity and volumetric water content has been subject of much research in the last 30 years [5]. For soil measurement, the dielectric constant is the ratio of the capacitance of the soil divided by the dielectric permittivity of free space. From the relationship of water content and permittivity, several empirical models exist. The empirical equation that relates to volumetric water content and dielectric constant of material has been derived as in equation (9) [11]:

$$\theta_v = A + B\varepsilon_a + C\varepsilon_a^2 + D\varepsilon_a^3 \qquad \text{eq. (9)}$$

where,

θ_v = the volumetric water content

ε_a = dielectric constant of material

For example, the parameters value for A = -8.63, B = 3.216, C = $-9.54\text{x}10^{-2}$, and D = $1.579\text{x}10^{-3}$ for most sands based on the calibration coefficients according to soil texture [11]. The parameters A, B, C, and D are differing for different types of soil texture and it is difficult to analyze. *Topp et al.* (1980) equation is used to provide a basis for comparison among soils [15]. The empirical equation by *Topp et al.* (1980) is generally applicable to coarse grained mineral soils [23]. Volumetric content from the range of 0 to 0.55 is used in the empirical relationship. Moreover, the empirical equation is widely used in determining the volumetric water content and dielectric constant in soil using TDR and oven-dry. Equation (10) shows that the empirical equation of third-order polynomial relationship based on volumetric water content and dielectric constant which is expressed by using equation (10) [10] [12] [18][23]:

$$\theta_v = -5.3 \times 10^{-2} + 2.92 \times 10^{-2}\varepsilon_a - 5.5 \times 10^{-4}\varepsilon_a^2 + 4.3 \times 10^{-6}\varepsilon_a^3 \qquad \text{eq. (10)}$$

Meanwhile, the calibration relationship for volumetric water content for most soil is expressed in refractive index model as in equation (11) [16] [23]:

$$\theta_v = a\sqrt{\varepsilon_a} + b \qquad \text{eq. (11)}$$

The coefficients value for a and b parameters fall within the range in TDR calibrations and the mean values of a = 0.110 and b = -0.180 [16]. The refractive index model is obtained by minimizing the sum of squared differences between the predicted permittivity and the permittivity according to equation (11) [23]. The refractive index model is a baseline equation developed as a reference for comparing different individual soil calibrations [16]. For *Topp et al.* (1980) empirical equation and refractive index model equation, only the real component of permittivity is considered. Soil bulk density and moisture content are taken into consideration in order to calculate volumetric water content value.

Besides, *Roth et al.* (1990) equation is based on dielectric mixing theory and requires knowledge of the dielectric constant of dry soil as well as its porosity [12][18]. The term α is required by dielectric mixing theory and accounts for the molecular orientation of the three materials in the system, namely air, soil, and water [9]. The expression for *Roth et al.* (1990) equation is determined in equation (12) [12] [18]:

$$\varepsilon_c = \left[\theta_v \times \varepsilon_w^{\alpha} + (1-\eta) \times \varepsilon_s^{\alpha} + (\eta - \theta_v) \times \varepsilon_a^{\alpha}\right]^{1/\alpha} \qquad \text{eq. (12)}$$

where,

ε_c = composite dielectric constant

ε_w = dielectric constant of water

ε_s = the dielectric constant of soil

ε_a = the dielectric constant of air

η = the soil's porosity and α = 0.46

CHAPTER 3
METHODOLOGY

3.1 Project Activities

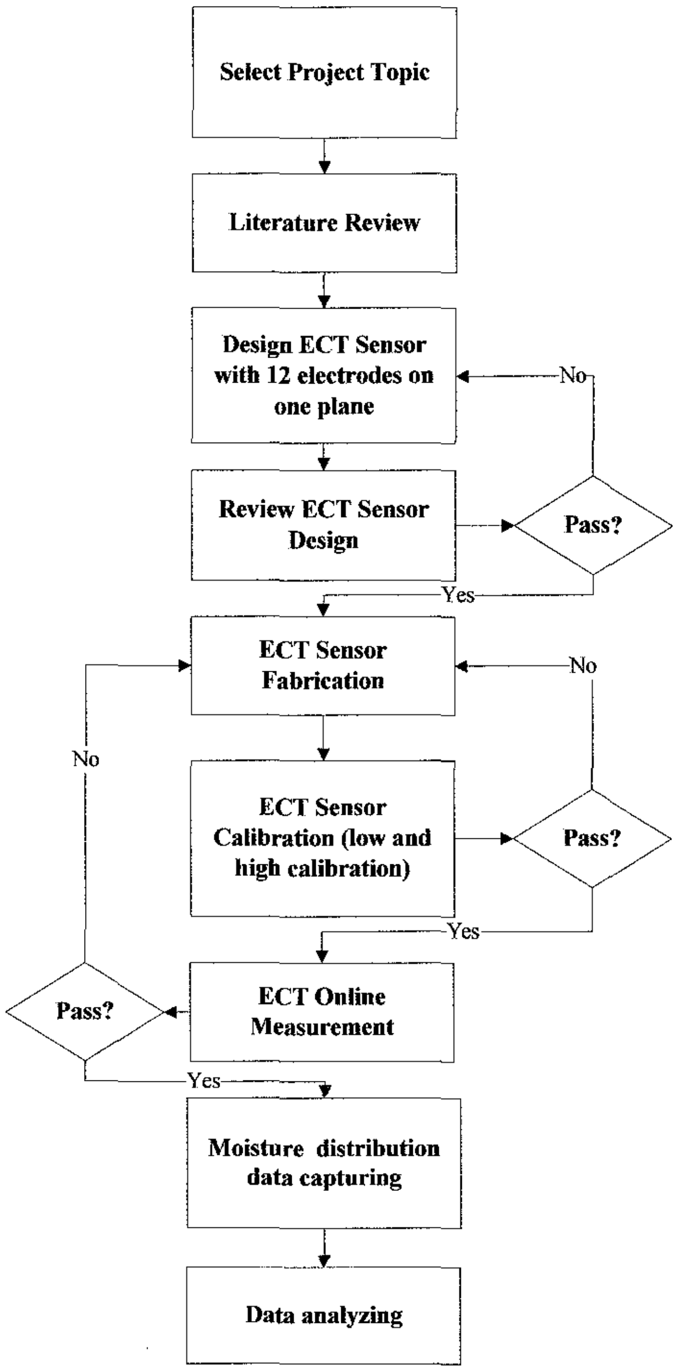
The topic of the project is selected based on the field and course taken that is Electrical and Electronic Engineering course so that the lesson learnt during the course is implemented. The literature review is done regarding the ECT and soil properties. There are journals and researches on ECT listed in the References portion of this report. The research methodology continues by designing capacitance sensor by using ECT concept. There are twelve electrodes in the sensor with copper foil or zinc plate as the conductive material. The electrodes are arranged in same level side by side as in Figure 5. The fabrication stage needs the hardware material to build the sensor such as insulating pipe as the body and holder of the sensor and copper foil or zinc plate as the conductive material for measurement portion.

The Industrial Tomography System (ITS) M3000 Multi-Modal Tomography System is used as a tool to calibrate the sensor and measure the online experimental data. The low and high calibration is conducted to ensure that the sensor and equipment are in good conditions. Moreover, the calibration is important in order to ensure the lowest and highest value of the measurement. When the online sensor measurement is conducted, the range for online measurement is in between the lowest and highest value obtained from the calibration. The low calibration is done by using lower permittivity material while high calibration is done by using higher permittivity material. The soil is ensured to be filled in the inner side of the ECT sensor where the measurement electrodes are located so that the measurement can be conducted.

Data acquisition and computer are used for data capturing and analyzing such as determining the capacitance and voltage values of the testing. The results are recorded and analysed. For data comparison, the oven-dry method is used and the experiment is conducted in the Civil Department laboratory. The oven-dry is a standard method used to test the percentage of moisture in soil according to ASTM 4643-08. 400g of soil is used in this oven-dry testing and the same amount of soil is used in ECT calibration and online measurement. The types of soil chosen in this experimental work are sand and clay. This is to observe the difference and comparison results in the moisture percentage data due to different soil texture in both soils that is the sand has larger soil particles size compared to clay.

The project activities are referred to key milestones attached in Appendix A. The project is divided into five phases which are literature review phase, fabrication phase, testing phase, data analyzing phase and closure phase. Each phase consists of several tasks to be completed for Final Year Project 2 within this. The first phase is done after the selection of the topic is made. Then after analysis on the sensor design and fabrication, the ECT sensor is fabricated according to the design criteria. The third phase is the testing phase that includes the calibration and online measurement for ECT sensor testing. The second phase is the data analyzing phase which covers the data analyzing obtained from the testing phase. Finally, the last phase is the closure phase where the oral presentation is held. From Figure 5 of project flow chart, the progress of the project reached until the ECT online measurement. At this stage, the author managed to calibrate and conduct online measurement by using sand as the measurement medium.

3.2 Procedure Identification



- Topic is selected based on the author's field of study (Instrumentation and Control System)
- Research on papers and journals regarding Electrical Capacitance Tomography (ECT).
- Design ECT sensor by considering the number of electrodes, earthed screen, and length of electrodes.
- Check if the designed sensor meets the ECT sensor requirements.
- Gather materials used to build ECT sensor as listed in hardware table.
- Use MMTS to conduct low and high calibration on the ECT sensor. Dry sand is used for low calibration while moist sand is used for high calibration.
- Conduct several test on ECT sensor by following the test procedure.
- Use ITS equipment and software to capture the data of moisture percentage distribution in the measuring area of ECT sensor.
- Analyze the data captured and compare with the results of the tests conducted.

Figure 5: Project Methodology Process Flow

3.3 Tools and Equipments Required

Devices and software that are available are used in the fabrication for the mechanism in obtaining desired result. Below is the list of software for the project:

Table 5: Software and hardware for sensor fabrication and testing

No.	Software/Hardware	Descriptions
1	M3000	Consists of MMTS, Cypress USB Device Driver Software, and ITS Software.
2	Polyvinyl chloride	Act as the body and holder of the sensor.
3	Copper tape	Act as the sensor for sensing moisture level in soil which is arranged in the circular shape in the outer side of the PVC.
4	Industrial Tomography System (ITS)	Conduct calibration, data acquisition, data processing, and data analyzing.
5	Data Cable and SMB plug	Data Cable and SMB plug gives connection from sensor (one SMB Cable for each electrode) to ITS electrodes plane.
6	Soldering iron and lead	Solder data cable terminal to copper tape.

3.4 Experimental Procedures

The experimental work has been conducted in the laboratory by using ECT system as the test apparatus. ECT sensor is connected to the data acquisition unit by using connectors that connect to the electrodes in ECT sensor via coaxial cables for 1-12 electrodes according to the plane arrangement on the device. The calibration procedure starts with the calibration of lower permittivity material that is dry soil and continued with higher permittivity material that is saturated soil. This calibration is important in order to measure the normalized capacitance value.

The online measurement is conducted after the calibration measurement has been performed. ECT sensor is filled with dry soil that is sand. An amount of water is added into the sand in the ECT sensor, which is 10ml, 20ml ..., and 400ml accordingly. The data is captured for time interval of 10 seconds. The relationship between the change in water content and the dielectric constant of the medium depends upon soil type and the frequency range of the measuring apparatus [7]. The same procedure is repeated for the several times for data comparison and analysis. Other than that, equation (7) is used in oven-drying method to determine the volumetric water content of the soil and identify the soil physical conditions.

Other than that, oven-drying method is a standard test method to determine the soil moisture content. Microwave heating is a process by which heat is induced within a material due to the interaction between dipolar molecules of the material and an alternating, high frequency electric field [22]. In oven-drying method, a sample of soil is dried in the microwave oven for 24 hours with 105°C temperature in order is to ensure that there is no moisture content exists in the sample soil. The weight of dry soil is measured as well as the weight of wet soil. According to ASTM D4643-08, the water content of soil can be calculated as in equation (13) and (14) [22]:

$$w = \frac{mass\ of\ water}{mass\ of\ ovendried\ soil} \times 100\% \qquad \text{eq. (13)}$$

$$w = \frac{m_1 - m_2}{m_2 - m_c} \times 100\% \qquad \text{eq. (14)}$$

where,

$w = \theta_m$ = the moisture content

m_c = the mass of container (g)

m_1 = the mass of container and wet soil (g)

m_2 = the mass of container and dry soil (g)

From equations (13) and (14), the moisture content value is substituted into equation (8) to determine the volumetric water content, θ_v by knowing the soil bulk density. Table 6 shows the calculation methods used for data comparison to calculate the moisture percentage, volumetric water content and dielectric constant for soil.

Table 6: Methods and equations

Methods	Equations
Topp et al. (1980) empirical model	$\theta_v = -5.3\times 10^{-2} + 2.92\times 10^{-2}\varepsilon_a - 5.5\times 10^{-4}\varepsilon_a^2 + 4.3\times 10^{-6}\varepsilon_a^3$ eq. (10)
Refractive index model	$\theta_v = a\sqrt{\varepsilon_a} + b$ eq. (11)
Oven-drying	$w = \frac{mass\ of\ water}{mass\ of\ ovendried\ soil}\times 100\%$ eq. (13) $w = \frac{m_1 - m_2}{m_2 - m_c}\times 100\%$ eq. (14)
Volumetric water content	$\theta_v = D_b \times \theta_m$ eq. (8)

Basically, the measurement method in this project consists of oven-drying method and ECT online measurement. According to ASTM D4643-08 oven-drying is a standard testing method in determining the soil moisture. In oven-drying method, the weight of the dry soil is measured as well as the weight of the wet soil. From the data obtained the percentage of soil moisture is calculated using equation (14). The ECT sensor is fabricated and calibration measurement is done to ensure that the lower and higher calibration value is correct. After that, the online measurement is conducted by adding an amount of water in the dry soil inside ECT sensor. The empirical model equations (11) and (12) are used as an approach to calculate the dielectric constant of the soil. This can be done by knowing the value of the volumetric water content in equation (8) that can be obtained from the product of percentage of moisture and soil bulk density.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Sensor Design

The sensor design was held after some research and understanding regarding the sensor. The material that is used in constructing the sensor is listed in Table 5.

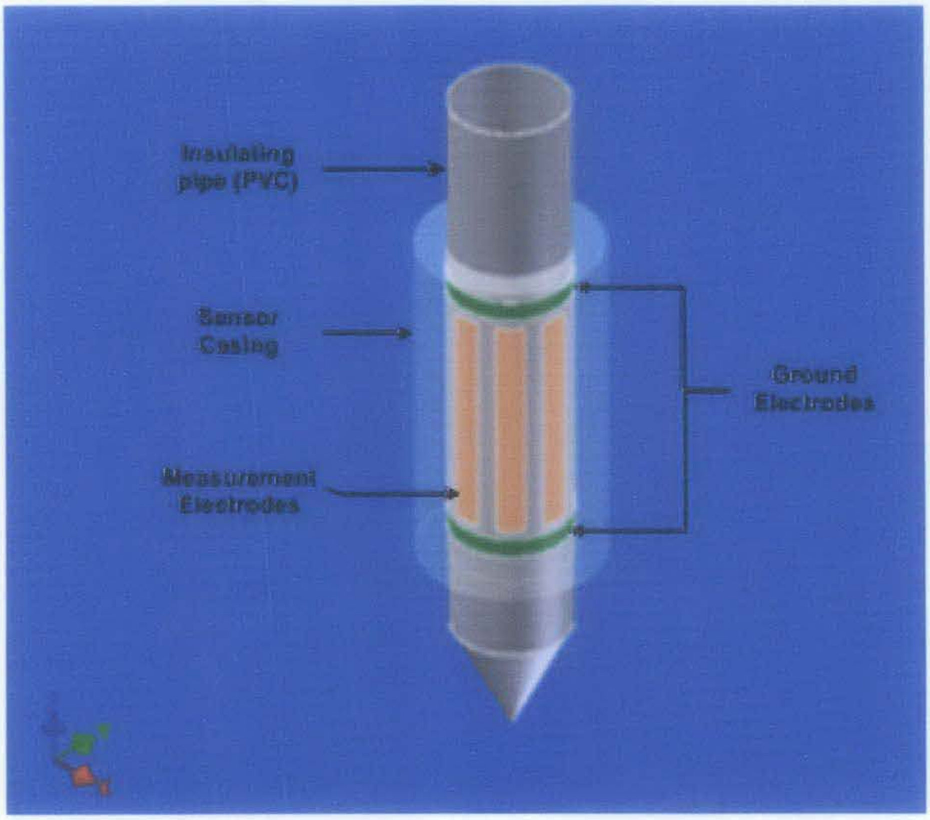


Figure 6: Sensor design with outer casing modelling

Figure 7 shows the elements that need to be considered in the sensor design are the material used for the body of the sensor that is the insulating pipe (PVC), the number of measurement and ground electrodes and the portion of each element need to be located. Figure 7 contains the visualisation of body of the sensor measurement and ground electrodes with the outer casing of the sensor. The outer casing is important because it protects the measurement and ground electrodes from direct contact with the soil when the test is conducted. It also acts as a shielding and has one layer of conductor which is connected with the ground electrode and reduces the noise when the measurement is made. Table 7 shows the specification lists of the ECT sensor that includes the number of electrodes, electrodes length, electrodes width, distance between two measurement electrodes, ground electrode width, inner and outer diameter of PVC.

Table 7: ECT sensor specification

No	ECT sensor components	Specifications
1	Number of electrodes	12
2	Measurement Electrodes length	10.00 cm
3	Measurement Electrodes width	1.00 cm
4	Distance between electrodes	0.60 cm
5	Ground Electrode width	1.00 cm
6	Inner PVC diameter	5.40 cm
7	Outer PVC diameter	6.00 cm

4.2 Sensor Fabrication

Below are the steps that the author used to fabricate the ECT sensor. In order to fabricate the sensor, the materials used in the project were gathered as listed in the Table 5.

Table 8: ECT sensor components fabrication steps

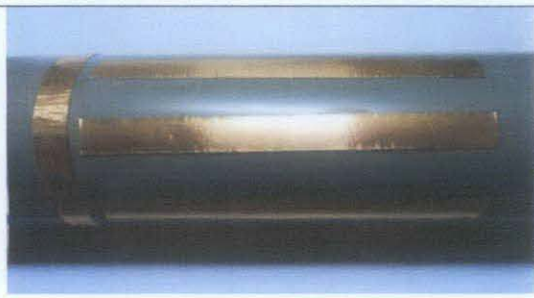
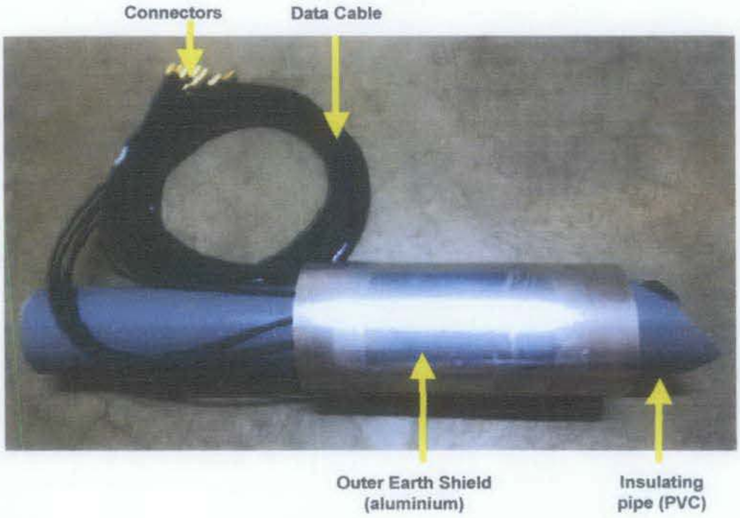
No	Steps	Images
1	Prepare the data cable with the SMB plug. The steps are: 1. Gather the SMB plug portion 2. Solder the SMB plug needle with the gold multi core wire in the data cable. 3. Assemble the SMB plug with the data cable.	1.  2.  3. 
2	Measure the PVC diameter and decide the length of the electrodes. Place the copper tape on the PVC. There is a ground electrode on top of the measurement electrodes plane.	
3	From the data cable, mount the silver multi core wire at the ground or earth electrodes portion while the gold multi core wire at the electrodes portion.	

Table 9: ECT sensor shielding fabrication

ECT Sensor	Descriptions
	ECT sensor with measurement electrodes and earth screen at both ends of the measurement electrodes.
	ECT sensor with outer earth shield which is connected with the earth screen that located at both ends of measurement electrodes.
	ECT sensor with outer shield to avoid direct contact for measurement electrodes and outer earth shield with soil.

From Table 8, it shows the steps involve in fabricating the ECT sensor. The fabrication consists of several portions such as the data cable, SMB plug, and the electrodes. Soldering technique was used to assemble most of the portion of the sensor. Table 9 shows the ECT sensor with 12 external electrodes that has been assembled with the electrodes, data cable, and SMB plug, earth screen, outer earth shied and outer shielding.

4.3 Calibration Measurement

The calibration was conducted by connecting the SMB plugs of 12 electrodes on the ECT sensor to the CTP1 plane of ITS device. The calibration procedure starts with the calibration of lower permittivity material that is dry soil and continued with higher permittivity material that is saturated soil. Figure 7 shows that the color scale of low and high calibration is differ from blue to red that is indicating '0' for low (blue) and '1' for high (red).

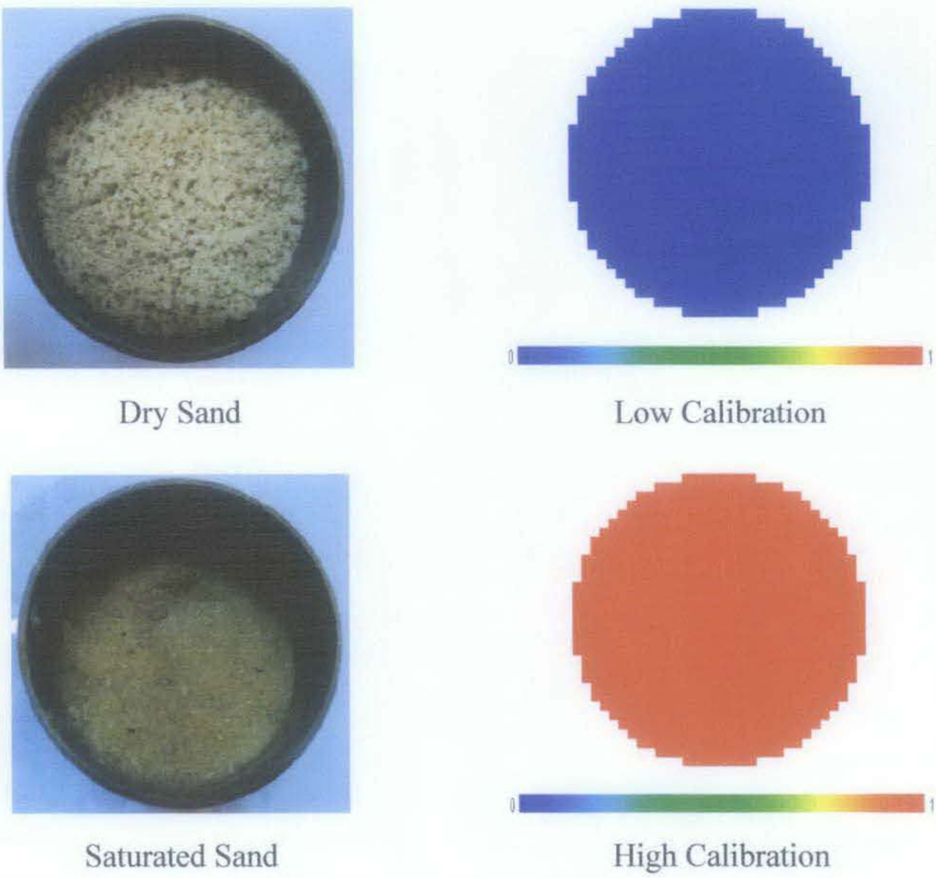


Figure 7: Low and high calibration images

4.4 Soil Preparation

Microwave heating is a process by which heat is induced within a material due to the interaction between dipolar molecules of the material and an alternating, high frequency electric field [22]. In oven-drying method, samples of sand are heated in a microwave oven and weighted in order to determine the moisture content in the sand. This is done by measuring the dry weight of the sand and compare with the wet weight of the sand. 400g of soil is used in this experimental work. An amount of water is added in the sand and the data is recorded. The volumetric water content of the sand is calculated using the volumetric water content equation. From the volumetric water content values, the dielectric constant can be determined. Figure 8 shows that the sample soil is ensured to be totally dry by inserting the samples of sand in the oven and then, the weight of the sand is measured.

The weight of the sample sand is measured

The samples of sand are dried by using oven so that no further water exist in the sand

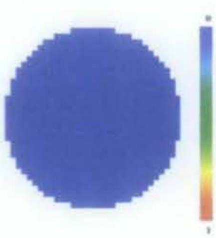
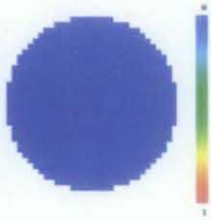
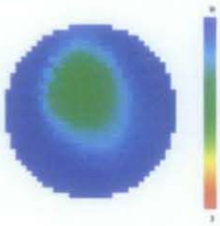
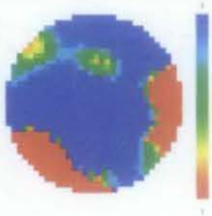
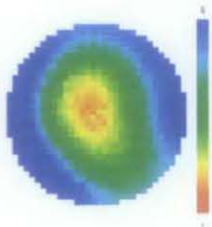
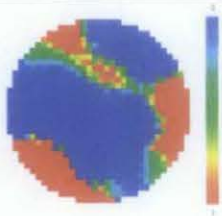
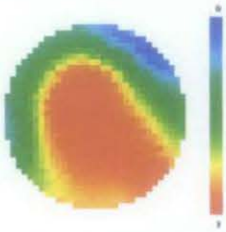
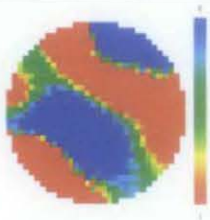
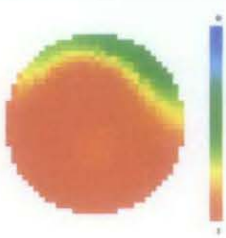
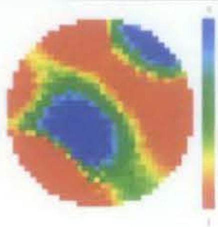
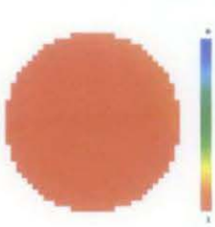
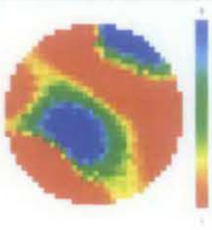
Figure 8: Samples of weighted and dried sand in the oven

4.5 Online Sensor Measurement

In the online sensor measurement, the soil moisture distribution for different volume of moisture content in the soil can be verified in Table 10. The types of soil used in this measurement are 400g sand and clay respectively. In this image distribution, the color scale shows that, the sensitivity of the electrodes in ECT sensor depends upon the volume of water and air in the soil. As the volume of water added increases, the moisture percentage increases and the color scale moves towards "1" or red color that indicates higher permittivity value of the test soils. It can be determined that the soil reaches its saturated value when the moisture content fills in all of the pore space in the soil. From the images shown in Table 10, it can be seen that the moisture distributions in sand are evenly distributed than clay. This is due to the soil properties itself where the sand has larger soil particles and pore space that allows the moisture to flow through it easily. Meanwhile, in clay, the moisture is hardly distributed when the volume of clay is larger than volume of moisture. A mixture of a lot of clay and small amount of volume of water results in a mixture that can be shaped.

From the ECT image distribution in Table 10 for sand, when 80ml water is added into dry sand, the percentage of moisture distribution obtained is 18.09% by calculating the color scale ratio in the ECT image pixel. The color scale changes from blue to light blue and light green that indicates the existence of minimum moisture content at that particular area. The color scale turns to red when the percentage of moisture in the sand 56.88% that is with 240ml water is added. It shows that the soil reaches its saturation value when the pore spaces of the soil are fully filled with water content. For the image of moisture distribution in clay it is lower than sand as the volume of water added increases because the water is hard to fill in the pore space in the small clay particles. The clay reaches its saturation level later than sand because clay has the ability to hold water longer than sand. Therefore, when 400ml of water is added in the clay, the image distribution shows that the clay has not reach its saturation level.

Table 10: Soil moisture distribution

Water volume (ml)	Image distribution		Percentage (%) of moisture distribution in ECT image pixel	
	Sand	Clay	Sand	Clay
0			0	0
80			18.09	17.03
160			36.22	33.43
240			56.88	51.50
320			76.13	72.65
400			97.30	91.02

4.6 Measurement Results

During the calibration measurement, the raw capacitance value for 66 independent capacitance measurements is recorded by ITS software. Therefore, by using normalized capacitance relationship for Maxwell, parallel and series, the normalized capacitance graph for measured capacitance value at 80ml of water is shown as in Figure 9. The value of normalized capacitance must not exceed 1 in order to obtain effective value for normalized capacitance. In the graph, the shape of the normalized capacitance plot is not smooth due to differ in capacitance range in the cross-section measurement area.

As stated in Table 3, the series model measures the water that exists in layer form while for parallel model, the water exists in column form and evenly distributed for Maxwell model. The series model has the highest differ in normalized capacitance value followed by Maxwell and parallel model. In the experiment, the water in the soil is assumed to be evenly distributed or exist in column form such that in Maxwell and parallel model. The error can be reduced by obtaining accurate calibration results for low and high calibration. Moreover the method used in the experimental procedure can be improved by ensuring that the amount of water poured in the soil is evenly distributed.

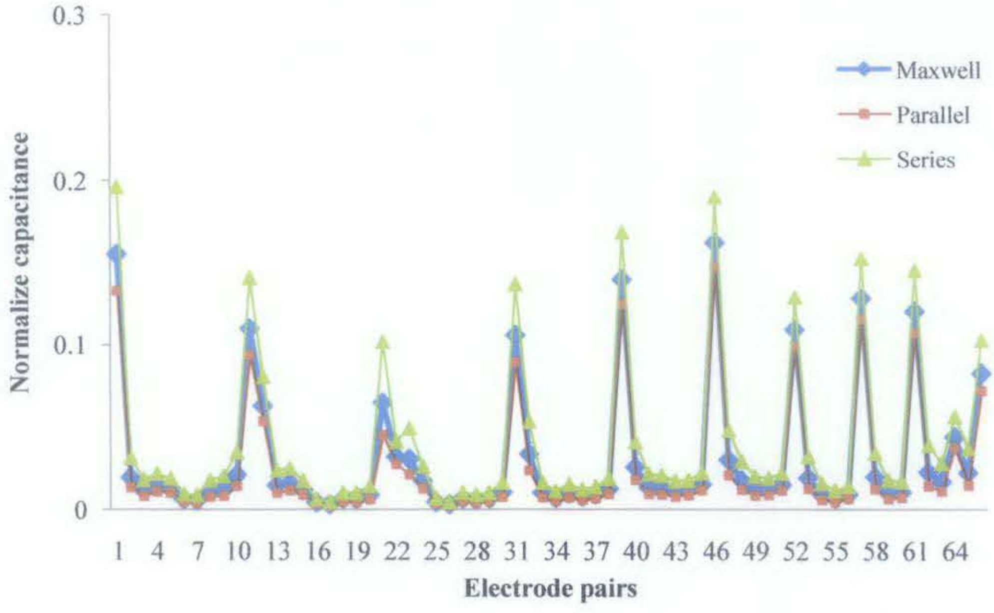


Figure 9: Normalize capacitance relationships

The relationships between dielectric constant and volumetric water content of the test sand and clay can be seen in Figure 10 and 11. The dielectric constant increases with increasing in volumetric water content. It is analysed by using *Topp et al.* (1980) empirical equation, refractive index model, oven-drying method, and ECT sensor online measurement data. From Figure 10 and 11, the online measurement data is plotted by using refractive index and empirical model equations. The online measurement data shows a positive increment in percentage of moisture content with respect to the dielectric constant. The dielectric constants in sand and clay have a close relationship with existence of moisture content in soil. When the moisture content fills in the soil particles, it reduces the volume of air content and increases the volume of moisture content in soil. There is some errors in the graph in Figure 10 and 11 but it can be improved by conducting better calibration and online measurement.

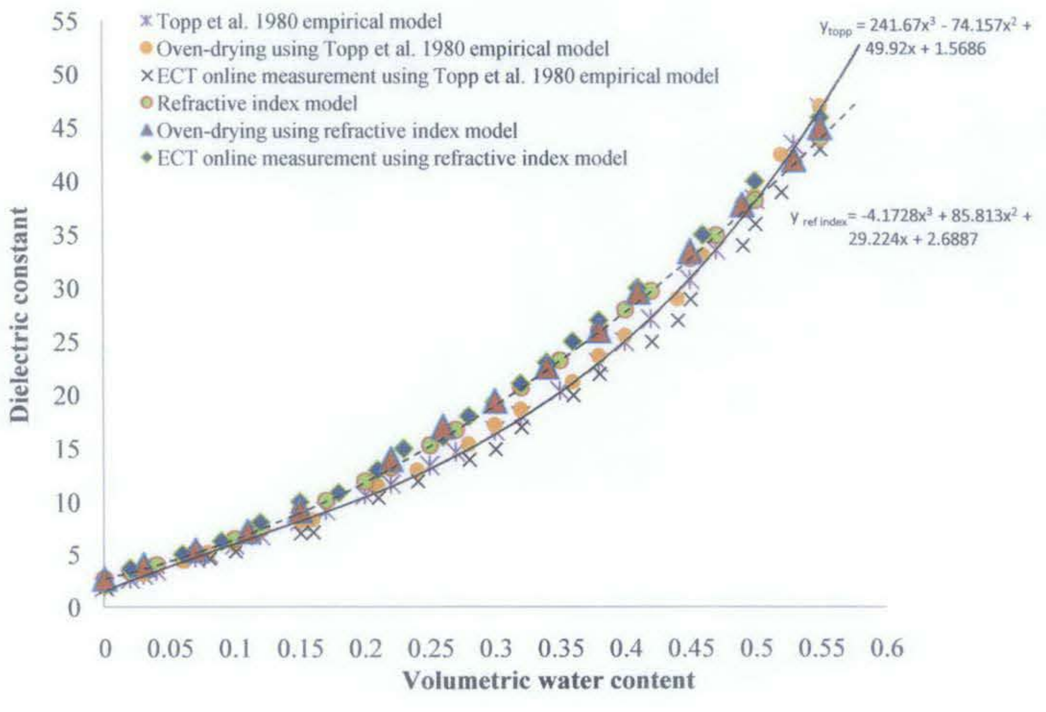


Figure 10: Dielectric constant versus volumetric water content in sand

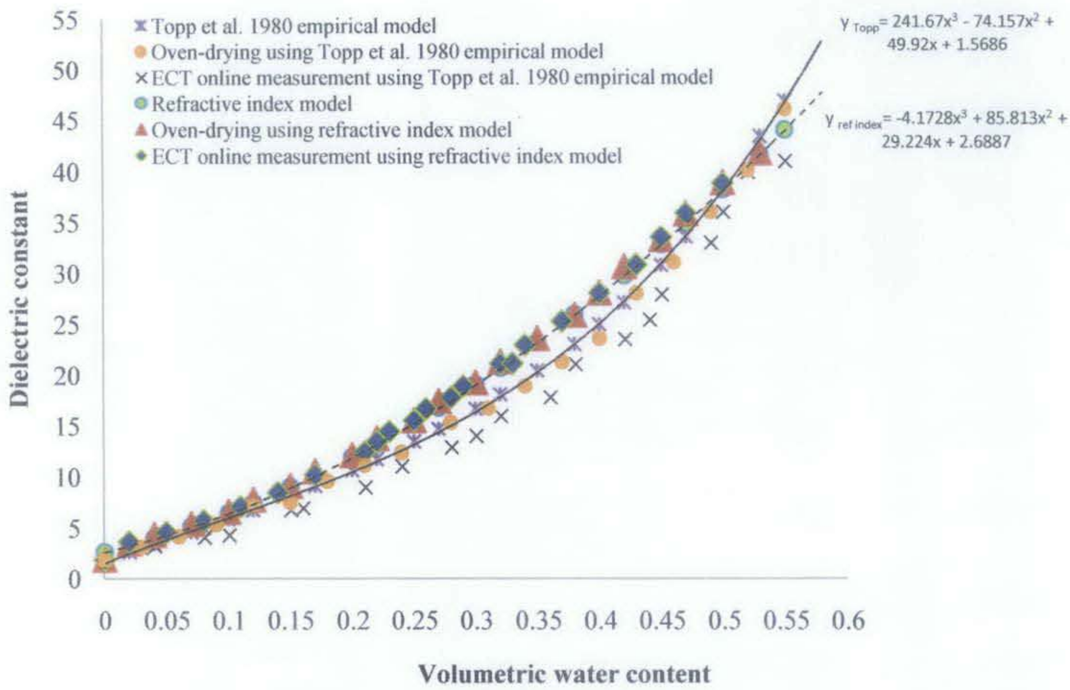


Figure 11: Dielectric constant versus volumetric water content in clay

4.7 Discussions

The ECT sensor was fabricated and consists of 12 electrodes and one ground or earth electrodes. The electrodes were placed outside the insulating pipe. The length of electrodes was chosen as 10 cm. This is to avoid the fringe effect of the ECT sensor. The fringe effect is where the line of flux leaps to one plate to the next plate thus affects the performance and value of the capacitance in the sensor. During the calibration, the sensor was held vertically and the section inside the electrodes was occupied by sand. Several tests were conducted during the low and high calibrations of the sensor. The low calibration used the medium of dry sand and the high calibration used moist sand as the medium. The average capacitance value is higher for high calibration than lower calibration. The difference in capacitance values is because the existing of water content in the soil for high calibration.

During the ECT online measurement, an amount of water is inserted in the soil and the image distribution is captured. As the volume of water increase in the soil, the color scale of the image distribution tends to move to red or "1". This indicates that the permittivity of the soil increases with increasing the water content in the soil. In order to compare the online measurement results, oven-drying method is used. The amount of water is expressed as a proportion by mass of the dry solid particles that is known as moisture content. The sand is dried in the oven with 105°C temperature to make sure that the sand is totally dry so that get accurate measurement can be obtained. In this experimental work, there is some error occurs in percentage of moisture distribution, volumetric water content and dielectric constant for online measurements. The errors are calculated by using oven-drying data obtained as the actual value measurement. The measured values are obtained from the data gathered in the online measurement. Oven-drying data is chosen because it is a standard method to determine the percentage of moisture in soil.

Table 11: Percentage of difference in moisture content for oven-dry and ECT

Water volume added in soil (ml)	Sand			Clay		
	Moisture content using oven-dry (%)	Moisture content using ECT (%)	Percentage of difference (%)	Moisture content using oven-dry (%)	Moisture content using ECT (%)	Percentage of difference (%)
80	20.00	18.09	1.91	20.00	17.03	2.97
160	40.00	36.22	3.78	40.00	33.43	6.57
240	60.00	56.88	3.12	60.00	51.50	8.50

Table 11 shows that there is some error occur in percentage moisture distribution in ECT online measurements for sand and clay. In oven-drying, the weight of dry soil is and the weight of the wet soil is measured. The percentage of moisture is calculated using equation (13) for this method. In ECT online measurement, the same amount of water is added into the soil and the image of moisture distribution is captured. By calculating the color scale in the image distribution, the percentage of moisture is obtained. From equation (13), when the weight of the dry soil is the same with the weight of the volume of water, the percentage of moisture percentage is 100% and the soil is said to be saturated. By observing the image of moisture distribution and the image pixel calculation of moisture percentage, the saturation level of the soil can be identified.

From both methods, the percentage difference is calculated by using oven-drying data as the true value since it uses a standard testing method in determining the percentage of moisture in soil and ECT online measurement data as the measured value. For example when 80ml is added in sand, 20% moisture content is obtained by calculating the moisture percentage. In ECT online measurement, when 80ml water is added in the sand, the moisture percentage is 18.09% which is calculated using the color scale in the image pixel. The percentage of difference is calculated using the moisture percentage values from both methods. The error occurs can be reduced by improving the calibration measurement and experimental procedure.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In the conclusion, the ECT sensor is fabricated and consists of measurement electrodes, earth screen at both ends of measurement electrodes, outer earth shield, and outer shielding to avoid direct contact with the measuring medium. The measurement electrodes are located outside the insulating pipe to prevent from direct contact with the soil inside the insulating pipe. Moreover, the earth screen and outer shield is used to avoid interferences between the sensor's applied signal and any devices present near the sensor. 12 measurement electrodes are chosen in order to obtain more independent capacitance measurement that is 66 measurements.

The calibration that includes low and high calibration is conducted by using lower permittivity material that is dry sand and higher permittivity material that is saturated sand. Totally dry sand is chosen as the lower permittivity material because its permittivity material value is lower when compared to saturated sand. Saturated sand has higher permittivity material value because the existence of water in the sand. The soil has pore space that enables it to hold water and air in its particles. Therefore when the ECT sensor calibrates totally dry soil, the permittivity value is lower than saturated sand because there is no water containing in the sand pore space.

In online measurement, the percentage of moisture content is measured by using oven-drying method and estimation of image pixel distribution in ECT. From the moisture content obtained in the oven-drying test, the data recorded is analysed and volumetric water content value is calculated. The empirical model is used as an approach in determining soil dielectric constant value and volumetric water content. By using *Topp et al.* empirical model equation and refractive index model, the dielectric constant is plotted in the graph such as in Figure 11 and 12. Preliminary result shows that there is a positive correlation with increasing water volume in the soil.

In the conclusion, monitoring soil moisture distribution is important in agriculture to ensure the plant growth. This experimental work has measured the soil moisture distribution by using 12 electrodes ECT sensor. The image of soil moisture distribution in ECT increasing from scale "0" to "1" that is from low to high as the percentage moisture content in soil increases. The dielectric constant of the test soils also increases with the increasing in the volumetric water content. Several methods have been used for data comparisons such as oven-drying method, data substitution in refractive index model and empirical model parameters.

5.2 Recommendations

The recommendation throughout the project is that the procedure of the experiment can be improved so that accurate data can be measured during the experiment especially in online measurement. In the current experiment procedure, the water is poured in the measured soil but for more accurate reading, the water need to be mixed evenly with the soil. Moreover, different type of soil can be used such as clay to analyse the different measurement data because the clay composition has the ability to hold the water content longer as compared to sand. The differing in the data obtained can be improved by identifying accurate data and good measurement procedures.

Other than that, it is recommended that the project can be improved by adding an intelligent system to the sensor so that the existence of the soil moisture can be detected. Moreover, this application can be applied to the agriculture application that has irrigation system. The system is recommended by using the ECT sensor as a detection device which detects the percentage of moisture in soil and sends signals to a control room via wireless transmitter so that the irrigation event and water content in soil can be controlled.

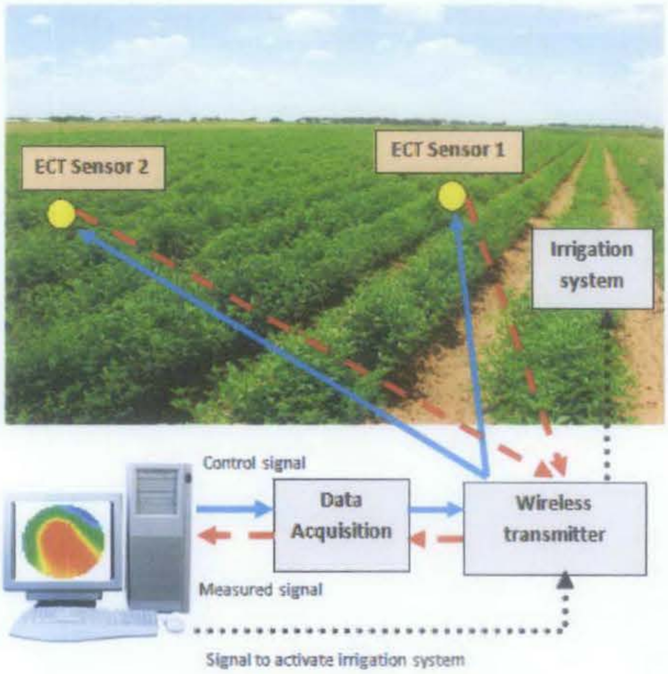


Figure12: Irrigation system with wireless transmitter and ECT sensor

5.3 Future Works

The experiment will be continued by using different types of soil. The experimental procedure will be improved by mixing the water and soil evenly before the measurement is made. Data analysis by using empirical models can be further analysed. The experimental data using ECT sensor will be analysed and compared with the data obtained from other method in determining moisture content. The irrigation control system by using ECT sensor as the soil moisture detection device and wireless transmitter as the signal transmitting device can be implemented and tested in the real agriculture environment.

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APPENDIX A

KEY MILESTONES

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15	16
1	Project Work Continue								**Mid Semester Break**									
2	Submission of Progress Report																	
3	Project work continue																	
4	Poster Exhibition																	
5	Submission of Draft Report																	
7	Submission of Dissertation (soft bound)																	
8	Oral Presentation (Viva)																	
9	Submission of Dissertation (Hard Bound)																	

Suggested milestones process

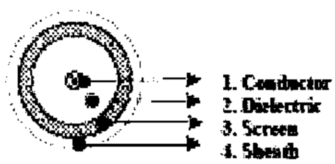
APPENDIX B

DATA CABLE

	TECHNICAL DATA SHEET	code	**MRG1740**
		version	**2**
		date	**2005-11-09**
	R.F. CABLE 50 OHM RG 174 U CCS	page	1/2

APPLICATION
Coaxial cable used for Radio-frequency, designed according MIL-C-17E/119F

CONSTRUCTION



1) Conductor	7x0.16 mm copper clad steel wire
Diameter	0.5 mm
2) Dielectric	Solid PE
Diameter	1.50 mm ± 0.10 mm
3) Screen	braid
Material	0.1 mm tinned copper wire
Diameter	1.97 mm ± 0.11 mm
4) Sheath	PVC
Diameter	2.80 mm ± 0.10 mm
Color	black

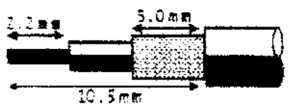
REQUIREMENTS AND TEST METHODS
Test methods generally in accordance with MIL-C-17E/119F

1) Conductor	
Elongation at break	≥ 1%
3) Screen	
Coverage	95 %

Electrical characteristics		
Mean characteristic impedance	50 ± 2 Ohm	
DC resistance inner conductor	≤ 317 Ohm/km	
Capacitance at 1 kHz	100 ± 3 pF/m	
Velocity ratio	0.66 ± 0.02	
Insulation resistance	> 10^{4} MOhm.km	
Voltage test of dielectric	3 kV dc	
Corona	≥ 1.5 kV ac	
Return loss at..	100 – 400 MHz	≥ 22.5 dB
	400 – 900 MHz	≥ 19.2 dB

APPENDIX C

STRAIGHT FEMALE CRIMP PLUG



Attributes

Attribute Type	Attribute Value
Gender	Jack
Mounting	cable
Orientation	Straight
Impedance Ω	50
Contact Plating	Gold
Contact Material	beryllium copper
Contact Termination Method	Solder
Cable Type	RG174A/U

Range Overview

SMB 50Ω Connectors in clamp and crimp termination options.
Reliable and quick connect/ disconnect system

Technical specification	
Working Voltage	250V max.
Proof Voltage	750V rms max.
Insulation Resistance	$>5 \times 10^9 \Omega$
Temperature Range	-65°C to +165°C

APPENDIX D

COPPER FOIL SHIELDING TAPE

Technical Data

Issue 2 / July 2006

AT526 35 Micron Copper Foil Shielding Tape

General description

35 micron copper foil coated with an electrically conductive acrylic adhesive supplied on a removable silicone liner.

- Conductive acrylic adhesive
- Good high and low temperature resistance
- Can be easily soldered
- Easy unwind

Specification

- Tested in accordance with ASTM D-1000 latest issue, BS EN 60454 - Part 2 test methods (Formerly VDE 0340, BS 3924.)
- Tested and meets military spcification MIL – T - 47012
- Construction is tested in-house and conforms to the Flame retardant requirement part only of UL510

Technical Details

Technical details	BS value	ASTM value
Typical values		
Foil thickness:	0.035mm	1.4 mil
Adhesive thickness:	0.025mm	1.0 mil
Total thickness:	0.060mm	2.4 mil
Adhesion to steel:	4.5 N/cm	41 oz/inch
Tensile strength:	40 N/cm	23 lbs/inch
Temperature Resistance:	-20°C to +155°C	Up to +311°F
Recommended curing cycle:	1 hour at 150°C or 2 hours at 130°C	
Electrical resistance through Adhesive*:	0.003 ohms	
RoHS compliant	Yes	
Storage Temperature	+12°C to +25°C	

*Tested according to MIL STD 202F method 307 across surface area of 1 sq. inch.

NOTE

Except where indicated otherwise, the figures stated are average values and should not be regarded as MAXIMUM or MINIMUM values for specification purposes. The Company reserves the right to improve products and any change in specification will result in a new issue of the relevant 'Technical Data Sheet'. Customers should satisfy themselves that the tape is suitable for their requirements whether after such modifications or otherwise. Please check that you have the latest issue of the 'Technical Data Sheet'. All slitting and length tolerances are to British Standards. Before use the customer is advised to consult the Health & Safety Data Sheet produced by the company for this product, which is available on request.

STORAGE

Tapes stored below the minimum recommended temperature will require warming up to that level before use. Up to 24 hours may be required for this to take place.

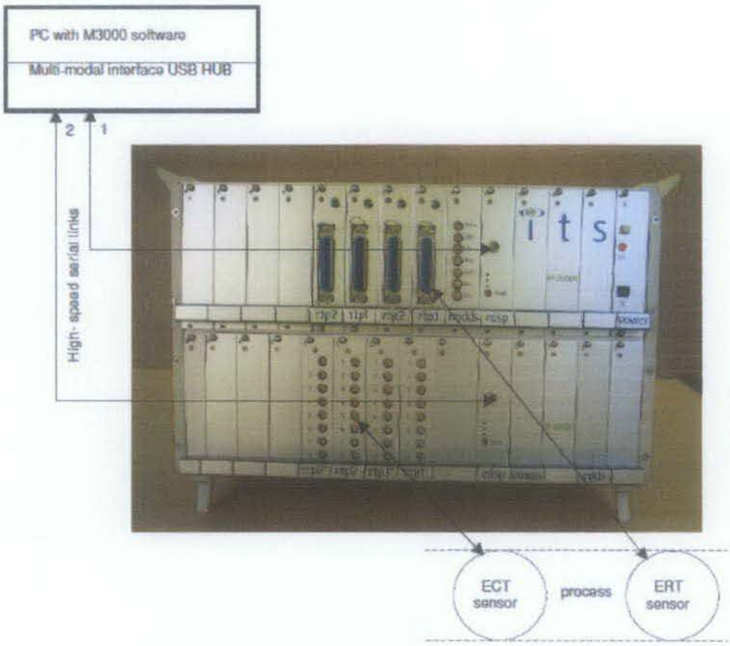
ADVANCE adhesive tapes

Advance Tapes International Limited, PO Box 122,
Abbey Meadows, Leicester, LE4 5RA.
Tel: 0116 251 0191. Fax: 0116 265 2046. www.advancetapes.com

AFERA
Association des Fabricants Europeens de Rubans Auto-Adhesifs.

APPENDIX E

INDUSTRIAL TOMOGRAPHY SYSTEM DEVICE



M3000-ECT

Number of electrodes	24; either 3 x 8, 2 x 12 or 1 x 24
Voltage injection method	Adjacent
Image reconstruction algorithm	Linear back projection (LBP)
Property of interest	Permittivity (ε)
Image spatial resolution	≈ 5-10%
Excitation methods	18 V pick-pick AC based sine wave voltage
Sinewave generator	DDS AD7008 with 32bit in zero order hold staircase wave
Oscillator	50 MHz
Microcontroller	DSP microcomputer ADSP-2181 with 3 operations per cycle
Clock speed	33 MHz
Memory	1 MB EPROM, 80 K bytes of on-chip RAM
Number of samples	PC programmable
Injection frequency	1 MHz
Injecting voltage	18 V (peak-peak)
Measurement range	0.001 +10 V (pp) with 80mV increment
Sensitivity	0.81 V/pF @ 5 fF change of 4.05mV
CMRR	> -120 db @ 1 MHz
Relative Accuracy measurement range	≈ 0.01-1 pF with one plane sensor
Signal to noise ratio (SNR) (at V_{ana})	56dB
Measurement stability at V_{output}	+/- 0.6mV
Mode of measurement	Sequential
Type of demodulation	Phase sensitive demodulation
Phase shift compensation	0° to 360° with 0.09° resolution
Speed of acquisition for one frame	20mS/F (digital demodulation @ 500 kHz for 12 electrodes)**
Communication interface	USB 2.0
Baud rate	480Mbits
Power consumption	DC 24 V 70W (power adapter output into DAS, +5V, +15V, -15V)
Size of PCBs	Eurocard
Power input from mains supply	100-240 V a/c, 50/60 Hz 1.5A

APPENDIX F

TECHNICAL PAPER

il Moisture Detection Using Electrical Capacitance Tomography (ECT) Sensor

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— This paper briefly discusses the measurement on soil e distribution using Electrical Capacitance Tomography echnique. ECT sensor with 12 electrodes was used for ition measurement of permittivity distribution. ECT vas calibrated using low and high permittivity material sand and saturated soils (sand and clay) respectively. The :ments obtained were recorded and further analyzed by .inear Back Projection (LBP) image reconstruction. iary result shows that there is a positive correlation with ng water volume.

vords-soil moisture distribution; ECT sensor; dielectric t; volumetric water content

I. INTRODUCTION

nation of soil moisture content is important in ure especially during irrigation scheduling. Changes in :entage of soil moisture during the irrigation event can rolled by indicating the amount of applied water to soil. ious monitoring of soil moisture content within and the rooting zone can facilitate optimal irrigation ing aimed at minimizing both the effects of water n the plants, and also leaching of water below the root nich can have adverse environmental effects [1].

his experimental work, ECT is used to measure soil e content based on the image of moisture distribution The soil moisture measurement is based on the concept dielectric constant in a dry material consisting soil s and air is relatively small (1.5 to 4) whereas the ic water constant is larger (80 at room temperature) he small amounts of water in soil cause the dielectric t of the resultant soil-water-air mixture to exhibit a ite dielectric constant that can be related to the soil e content through a simple calibration procedure [15].

ie-domain reflectometry (TDR) method, frequency- reflectometry (FDR) method, amplitude-domain metry (ADR) method and capacitive method are the methods available for the electrical measurements of :lectric constant [12]. E.g. TDR instruments use ed pulse travel times to determine the apparent soil ic permittivity [14]. Some of the researchers found that acitance probe method was independent of soil type wide ranges of soil moisture levels [2]. However, these s do not determine the image distribution of the moisture in the soil. In ECT, the image distribution of permittivity material can be seen in the form of image pixel depending on the scale of the permittivity material from lowest to highest value. ECT has been developed since 1980s for visualization and measurement of a permittivity distribution in cross section using a multi-electrode capacitance sensor [21]. The ECT sensor measures the distribution of permittivity of the soil moisture inside the insulating frame and captures the image distribution and measurement data.

II. SOIL MOISTURE

Soil moisture content impacts crop growth directly and also influences the fate of agriculture chemicals applied to soil [20]. One of the key components in managing irrigation scheduling is by determining the moisture content in soil. Zazueta and Xin (1994) reported that soil moisture content may be determined via its effect on dielectric constant by measuring the capacitance between electrode pairs implanted in the soil [7]. Other than that, the soil physical condition plays an important role in soil moisture determination. In normal soil condition, air and water are filled in the pore spaces of soil, thus the dielectric constant of the soil-water-air mixture can be measured. The dielectric constant for air is 1 while dielectric constant of water is 80 (room temperature). When volume of water content in the pore spaces increases, the dielectric constant of the soil will increase. Fig. 1 shows that the unsaturated soil is composed of solid particles, organic materials and pores [4]. The pore spaces of the soil contain air, water and root.

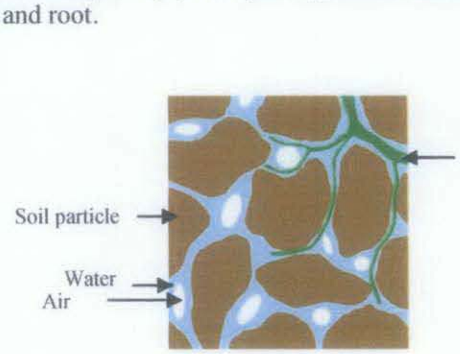


Figure 1. Illustration of soil physical contains soil particles, water, air and plant's root [4].

terminology of moisture content stated in ASTM 08 is the ratio, expressed as percentage, of the mass of or "free" water in a given mass of soil to the mass of d particles [19]. The moisture content in soil can be d by knowing the soil physical conditions of the soil. l's bulk density, D_b is weight of dry soil to the unit (solids and pore). Particle density, D_p involves ng the weight of dry soil and the volumetric soil i.e. only solid and no pore space. From both bulk and particle density values, the soil porosity can be ed by using equation (1) [6] [17]:

$$Soil\ porosity = 1 - \frac{D_b}{D_p} \quad (1)$$

sture content, θ_m determines the amount of water with ı mass of soil. Moisture content is calculated by ; the weight of water in the soil by the weight of dry ie expression of water content in terms of volume of ıer volume of soil can be determined as volumetric ɔntent, θ_v using equation (2) [6] [17]:

$$\theta_v = D_b \times \theta_m \quad (2)$$

n the ratio of volumetric water content and soil ', the amount of pores filled with water i.e. soil ɔn can be calculated.

III. ECT

lustrated ECT system shown in Fig. 2. consists of ECT vith 12 electrodes for soil moisture as detection device, ɪuisition unit to process data, and a personal computer ı storage, image processing and display. In ECT the ː in inter-electrode capacitance due to the change in ration and/or distribution of dielectric materials in the ɪre measured, and a cross-sectional image representing ·mittivity distribution inside a pipe or vessel is ·ucted [16].

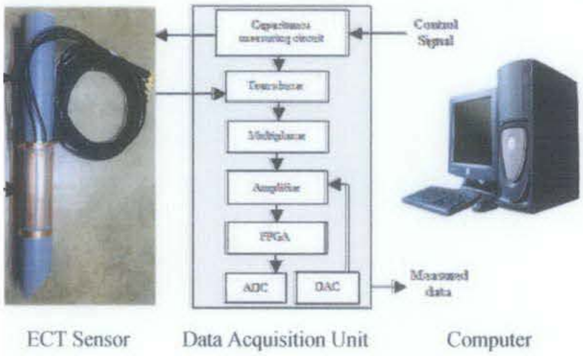


Figure 2. ECT system.

A. ECT Sensor

There are several components need to be considered in designing ECT sensor. ECT sensor consists of four main parts [21]:

- Measurement electrodes.
- Outer, axial end and radial screens.
- An insulating frame.
- Coaxial cables and connectors.

The basic method is to surround the vessel or insulating frame with a set of electrodes (metal plates) and the capacitance measurements is measured between each unique pair of electrodes. Typically, measurement electrodes of ECT sensor are placed outside insulating frame with two axial ends and outer screen. Two earthed axial end screens at both ends of the measurement electrodes can reduce external noise to some extent and have a negative effect on capacitance measurement because the electrical field is dragged to the earthed axial end screens [21]. Coaxial cables and connectors are used to connect ECT sensor to the data acquisition unit. Key elements in ECT are the number of electrodes, length of electrodes, external or internal electrodes, earthed screens, and driven guard electrodes. The details of the key elements in ECT sensor are discussed by Yang (2010) [21].

In this experimental work, ECT sensor of 12 electrodes was constructed with electrodes length of 10.0cm and 1.0cm width, and the space between a pair of electrode is 0.6cm. The electrodes are mounted outside the insulating frame of 6.0cm diameter. There are two axial ends in the sensor which act as grounding portion. The material for outer earth shielding is aluminum. The outer shielding is connected with two axial ends as grounding purposes. Two types of measurement in ECT system are calibration and online measurements. ECT sensor is calibrated using two different test mediums as low permittivity material (dry soil) and high permittivity material (saturated soil). In online measurement, the ECT sensor is filled with soil and known amount of water is added in the soil.

The calibration in lower and higher permittivity material gives lower and higher capacitance (C_l and C_h) values respectively while online measurement gives measured capacitance value, C_m. All subsequent measured capacitance values, C_m are then normalized to have values, C_n between "0" (when the sensor is fully filled with the lower permittivity material) and "1" (when fully filled with higher permittivity material) according to the equation (3) [22]:

$$C_n = \frac{C_m - C_l}{C_h - C_l} \quad (3)$$

'a Acquisition System

ι acquisition unit measures the capacitance between e pairs and converts the measurement data into an ɔermittivity distribution. The high speed USB cable s the data acquisition unit to the control computer. ɔm the unit is then sent out to a control computer for ɔrage, processing and display. According to Yang to obtain a complete set of data for one image, e 1 is used for excitation and electrodes 2-12 for n, obtaining 11 capacitance measurements [21]. The of independent capacitance measurements can be ed by $N (N-1)/2$, where N is the number of electrodes. on the number of independent capacitance ɜments equation, there are 66 independent capacitance ɜments for 12 electrodes in ECT sensor.

IV. IMAGE RECONSTRUCTION

e of permittivity distribution in 12 electrodes ECT vith 66 independent measurements is projected onto a square pixel grid. On a (32x32) square pixel grid there 4 pixels, but only 812 pixels are needed to construct s-sectional image of the vessel [18]. With 812 pixels, ɜ remaining pixels that are not being used because they ted outside the measurement area. The color scale used blue to red i.e. "0" to "1" to indicate the range of the ermittivity material to higher permittivity material. In ıe measuring capacitance between two electrodes can ɜssed by the following integral equation (4) [11]:

$$C = \iint_D G(x,y) \cdot S(x,y,G(x,y))dxdy \quad (4)$$

of the most commonly used reconstruction algorithm ɡe reconstruction in ECT system is the LBP because it ımplest and fastest system for image reconstruction . The LBP has been implemented to reconstruct images T sensor using 12 electrodes and transducer-based ɔcessor system [3]. With LBP, the permittivity tion in ECT can be determined. The relationship can be linear normalized form as in equation (5) [11]:

$$C = SG \quad (5)$$

C is the normalized capacitance matrix, S is the ɜer sensitivity matrix which contains the set of ity matrices for each electrode pairs, and G represents nalized permittivity. The product of G is multiplication ranspose of the transducer sensitivity matrix with the zed capacitance matrix.

V. DIELECTRIC CONSTANT MEASUREMENT

For soil measurement, the dielectric constant is the ratio of the capacitance of the soil divided by the dielectric permittivity of free space. The relationship between the changes in water content and the dielectric constant of the medium depends upon soil type and the frequency range of the measuring apparatus [1]. From the relationship of water content and permittivity, several empirical models exist. The empirical equation that relates to volumetric water content and dielectric constant of material has been derived as in equation (6) [9]:

$$\theta_v = A + B\varepsilon_a + C\varepsilon_a^2 + D\varepsilon_a^3 \quad (6)$$

where θ_v is the volumetric water content, and ε_a is dielectric constant of material. E.g. the parameters value for $A = -8.63$, $B = 3.216$, $C = -9.54\text{x}10^{-2}$, and $D = 1.579\text{x}10^{-3}$ for most sands based on the calibration coefficients according to soil texture [9]. The parameters A, B, C, and D are differing for different types of soil texture and it is difficult to analyze. *Topp et al.* (1980) equation is used to provide a basis for comparison among soils [13]. The empirical equation by *Topp et al.* (1980) is generally applicable to coarse grained mineral soils [20]. Volumetric content from the range of 0 to 0.55 is used in the empirical relationship. Moreover, it is widely used in determining the volumetric water content and dielectric constant in soil using TDR and oven-dry. Equation (7) shows the empirical equation of third-order polynomial relationship based on volumetric water content and dielectric constant which is expressed by using equation (7) [8] [10] [15][20]:

$$\theta_v = -5.3\times10^{-2} + 2.92\times10^{-2}\varepsilon_a - 5.5\times10^{-4}\varepsilon_a^2 + 4.3\times10^{-6}\varepsilon_a^3 \quad (7)$$

Meanwhile, the calibration relationship for volumetric water content for most soil is expressed in refractive index model as in equation (8) [14] [20]:

$$\theta_v = a\sqrt{\varepsilon_a} + b \quad (8)$$

The coefficients value for a and b parameter fall within the range in TDR calibrations and the mean values of $a = 0.110$ and $b = -0.180$ [14]. The refractive index model is obtained by minimizing the sum of squared differences between the predicted permittivity and the permittivity according to equation (8) [20]. The refractive index model is a baseline equation developed as a reference for comparing different individual soil calibrations [14]. For *Topp et al.* (1980) empirical equation and refractive index model equation, only the real component of permittivity is considered. Soil bulk density and moisture content are used to calculate volumetric water content value.

VI. EXPERIMENTAL DESCRIPTIONS

relationship between apparent soil permittivity and ric water content has been subject of much research in t 30 years [5]. The experimental work has been ed in the laboratory by using ECT system as the test ıs. ECT sensor is connected to the data acquisition unit g connectors that connect to the electrodes in ECT ia coaxial cables for 1 to 12 electrodes according to the rrangement on the device. The calibration procedure ith the calibration of lower permittivity material i.e. dry d continued with higher permittivity material i.e. d soil. This calibration is important in order to measure nalized capacitance value, C_n as in (3). Calibration is ed as lowest and highest set point values for online ement data.

online measurement is conducted after the calibration ement has been performed. ECT sensor is filled with i.e. sand or clay (filled inside the insulating frame as ed in Fig. 3). An amount of water is added into the soil CT sensor, i.e. 10ml, 20ml …, and 400ml accordingly. a is captured for time interval of 10 seconds. The same re is repeated for the several times for data comparison lysis. From soil moisture distribution image in ECT, the ge of the soil moisture in the image pixel is calculated ring to the color scale of from "0" to "1". The moisture ge and bulk density is used to calculate the volumetric ontent, θ_v of the test soil.

er than that, oven-drying method is a standard test to determine the soil moisture content. The oven-technique is probably the most widely used of all tric methods for measuring soil moisture [7]. ave heating is a process by which heat is induced a material due to the interaction between dipolar es of the material and an alternating, high frequency field [19]. In oven-drying method, a sample of soil is n the microwave oven for 24 hours with 105°C ture in order is to ensure that there is no moisture exists in the sample soil. The weight of dry soil is d as well as the weight of wet soil. According to D4643-08, the water content of soil can be calculated as ı (9) and (10) [19]:

$$w = \frac{mass of\ water}{mass of\ ovendried soil} x100\% \tag{9}$$

$$w = \frac{m_1 - m_2}{m_2 - m_c} x100\% \tag{10}$$

v can be denoted as θ_m i.e. the moisture content, m_c is s of container (g), m_1 is the mass of container and wet and m_2 is the mass of container and dry soil (g). From (10), the moisture content value is substituted into (2) ılate the volumetric water content, θ_v by knowing the k density. The volumetric water content from online ement in ECT and oven-drying methods can be ted into empirical equations to calculate the dielectric t measurement.

VII. RESULTS

A. ECT Calibration Measurement

The tomogram image has its unique color scale i.e. blue that indicates "0" (low permittivity material) and red indicates "1" (high permittivity material). In between blue to red there are other colors indicating different scale from 0.001 to 0.999 approximately. Fig. 3 shows lower calibration using dry sand and saturated sand for high calibration while Fig. 4 shows the image of the calibrations.

Low calibration (dry sand) High calibration (saturated sand)

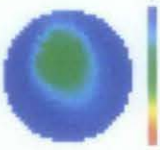
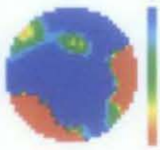
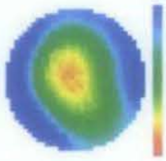
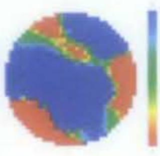
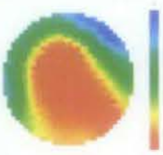
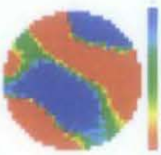
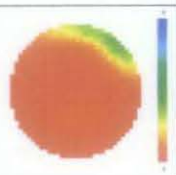
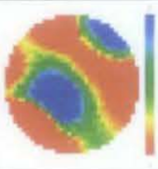
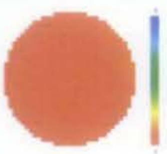
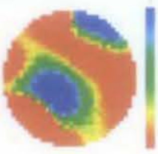
Figure 3. Low and high calibration for sand.

Figure 4. Low and high calibration images.

B. ECT Online Measurement

In online measurement, the soil moisture distribution for different volume of water content in soil can be verified in TABLE I. The types of soils used in this measurement are sand and clay. In this image distribution, the color scale shows that, the sensitivity of the electrodes in ECT sensor depends upon the volume of water and air in the soil. As the volume of water added increases, the moisture percentage increases and the color scale moves towards "1" or red color that indicates higher permittivity value of the test soils. It shows that the soil reaches its saturation value when the pore spaces of the soil are fully filled with water content. From the images shown in TABLE I, it can be seen that the moisture distributions in sand are evenly distributed than clay. This is due to the soil properties itself where the sand has larger soil particles and pore spaces that allows the water to flow through it easily. Meanwhile, in clay, the water is hardly distributed when the volume of clay is larger than volume of water. A mixture of higher volume of clay and smaller amount volume of water results in a mixture that can be shaped.

BLE I. IMAGE OF SOIL MOISTURE DISTRIBUTION IN ECT

ECT image distribution		*Percentage of moisture distribution in ECT image pixel (%)*	
Sand	***Clay***	***Sand***	***Clay***
		0	0
		18.09	17.03
		36.22	33.43
		56.88	51.50
		78.13	72.65
		97.30	91.02

ı the ECT image distribution in TABLE I, when 80ml ; added into dry sand, the percentage of moisture ion obtained is 18.09% by calculating the color scale the ECT image pixel. The changes in color scale ; an existence of water content in that particular area. or scale turns to red when the percentage of moisture ınd 56.88% i.e. with 240ml water is added. This result ıat the percentage of moisture increases as the volume added in the sand increases. The saturation level is d when the pore spaces in the sand is fully filled with For the image of moisture distribution in clay, the ge of moisture is lower than sand. The clay reaches its n level later than sand. In this case, when 400ml of added in the clay, the image distribution shows that has not reach its saturation level.

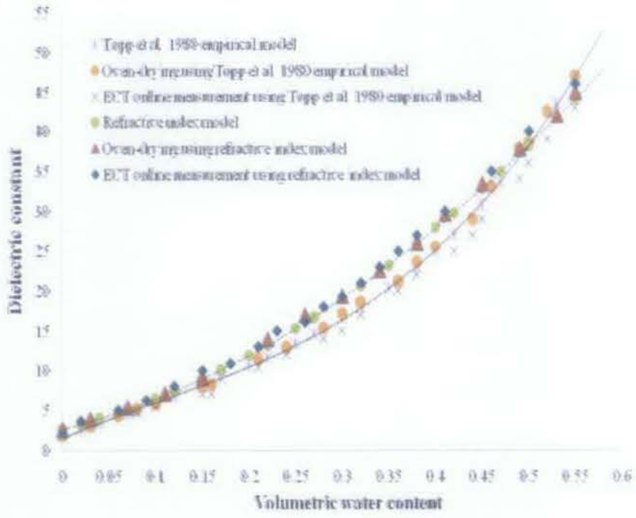


Figure 5. Dielectric constant versus volumetric water content graph for sand.

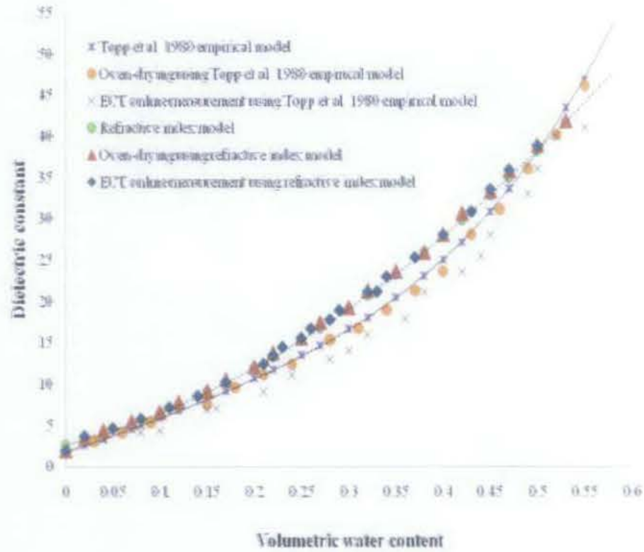


Figure 6. Dielectric constant versus volumetric water content graph for clay.

The relationships between dielectric constant and volumetric water content of the test soils i.e sand and clay can be seen in Fig. 5 and 6. The dielectric constant increases with increasing in volumetric water content. It is analyzed by using empirical equations, oven-drying method, and ECT sensor online measurement data. From Fig 5 and 6, the online measurement data is plotted by empirical model equations. The online measurement data shows a positive increment in percentage of moisture content with respect to the dielectric constant. The dielectric constants in sand and clay have a close relationship with existence of water content in soil. When the water content fills in the pore spaces, it reduces the volume of air and increases the volume of water in soil.

.E II. PERCENTAGE OF DIFFERENCE IN OVEN-DRY AND ECT

Sand			Clay		
Moisture content using oven-dry (%)	*Moisture content using ECT (%)*	*Percentage of difference (%)*	*Moisture content using oven-dry (%)*	*Moisture content using ECT (%)*	*Percentage of difference (%)*
20.00	18.09	1.91	20.00	17.03	2.97
40.00	36.22	3.78	40.00	33.43	6.57
60.00	56.88	3.12	60.00	51.50	8.50

.E II shows that there is some error occurs in ıge moisture distribution in ECT online measurements l and clay. In oven-drying, the weight of dry soil is and ght of the wet soil is measured. The percentage of e is calculated using (10) for this method. In ECT neasurement, the same amount of water is added into and the image of moisture distribution is captured. By ing the color scale in the image distribution, the ıge of moisture is obtained. From both methods, the ıge difference is calculated by using oven-drying data true value since it is a standard testing method in ning the percentage of moisture in soil and ECT online :ment data as the measured value. E.g. when 80ml is in sand, 20% moisture content is obtained by ing the moisture percentage. In ECT online :ment, when 80ml water is added in the soil, the e percentage is 18.09% which is calculated using the ale in the image pixel. The percentage of difference is ed using the moisture percentage values from both s. The error occurs can be reduced by improving the ion measurement and experimental procedures.

VIII. CONCLUSION AND FUTUREWORK

e conclusion, monitoring soil moisture distribution is nt in agriculture to ensure the plant growth. This ıental work has measured the soil moisture distribution ; 12 electrodes ECT sensor. The image of soil moisture tion in ECT increasing from color scale "0" to "1" i.e. wer to higher permittivity material as the percentage of e content in soil increases. The dielectric constant of soils increases with the increasing in the volumetric :ontent. Several methods have been used for data isons such as oven-drying method and data substitution ıpirical model equation. The differing in the data 1 can be improved by identifying accurate data and easurement procedures. The data of this research will l as reference to measure moisture content in soil ly in imaging application. This paper is part of ; research. The wide applications of ECT can be in various field in the industry e.g. in monitoring n event in agriculture.

ACKNOWLEDGMENT

hors would like to thank Areeba Shafquet for assisting :rimental work in the laboratory during this research.

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