SOIL MOISTURE DETECTION USING ELECTRICAL CAPACITANCE TOMOGRAPHY SENSOR (ECT)

By

SITI NOR FARHANAH BINTI MOHD FUAD

FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronics Engineering
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

SOIL MOISTURE DETECTION USING ELECTRICAL CAPACITANCE TOMOGRAPHY SENSOR (ECT)

by

Siti Nor Farhanah binti Mohd Fuad

A project dissertation submitted to the
Department of Electrical & Electronics Engineering
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

____

IR. DR. IDRIS BIN ISMAIL
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

September 2012

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.

____

SITI NOR FARHANAH BINTI MOHD FUAD

ABSTRACT

Soil moisture content determination is a common process in agriculture which needs sensors with high accuracy and compatibility with the environment. The available methods are described with attention given to the gravimetry measurement, lysimeters, neutron scattering, gamma absorption, time domain reflectometer, electrical resistance blocks, and electrical tomography sensors. Current technique used is time domain reflectometer which is convenient and reliable. However, this device is quite expensive and cannot provide clear view of moisture percentage distribution in soil. The proposed sensor which is using tomographic method, can visualize data using permittivity distribution. By using an array of sensors that are positioned around the pipe, it is possible to visualize the percentage of soil moisture. Electrical Capacitance Tomography (ECT) is comparatively low cost and capable to make measurements rapidly. The mechanism used in ECT is non-invasive, inert, and non-ionizing. The report consists of an introduction, problem statement, objectives, literature review and methodology used to solve the problem. It further looks into the obtained results with consistent discussion.

ACKNOWLEDGEMENTS

I would like to begin by expressing my gratitude to Allah s.w.t. for His blessing. Without His bless, this Final Year Project (FYP) will not be successful. My deepest appreciation goes to my supervisor, Ir. Dr. Idris bin Ismail for the continuous guidance, support, and encouragement from the beginning until the final phase of the project. I would also like to thank all committee members of Final Year Project for their respective professionalism, contribution, and support in providing quality education during the execution of this project. My special thanks goes to all technicians and postgraduate students for their help, guidance and advise throughout the project. Last but not least, not forgetting my family members and friends, thanks for their never ending support and motivation.

TABLE OF CONTENTS

List of Figures

List of Tables

List of Abbreviations

ECT	Electrical Capacitance Tomography
ERT	Electrical Resistance Tomography
EMT	Electromagnetic Tomography
TDR	Time Domain Reflectometer
LBP	Linear Back Projection
ITS	Industrial Tomography System

List of Nomenclatures

M	Number of independent measurements
n	Number of electrodes

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Soil moisture content is a key factor for the survival of all plants growth, especially in irrigated systems for greenhouse vegetable production. Lack of information about the soil moisture status can lead the plant to over-irrigate or under-irrigate. The effect of over irrigation may damage the crop and reduce the quantity and quality of the vegetable production, wasting of water, and problems might occur which are related to extremely wet soil for instance water logging, leaching of nutrients, increasing the numbers of plant disease and reduced usage of daily water. Meanwhile decreasing of moisture content will cause declining of photosynthesis process of the plant. Besides, under irrigation will give rise to difficulties for the plant root system to absorb nutrients in order to maintain transpiration rates. As the consequences, decreasing in cell production will occur.

To develop an irrigation scheduling program, the understanding of relationship between the plant and moisture content is important. Therefore, the soil moisture content must be measured accurately and continuously in order to minimize and thus prevent the effect of poor irrigation. This can be achieved by using tomographic technique. Tomography is a system that is related to cross-sectional images of an object. The process of tomography is simply a process to gain plane section images of particular object.

Process tomography instrumentation is low cost and able to make quick measurements. Array of sensors that are located around the vessel or pipe is feasible to capture the concentration or percentage and movement of the materials inside. Measurements are reconstructed to form two-dimensional images, besides to provide information in monitoring process thus improve results, value, effectiveness, and overall control. Tomography systems is useful in various types of processes and unit operations, including agriculture scheme, stirred reactors, pipelines, fluidized beds, mixers, and separators. According to the sensing device used, tomography system

The environment inside the greenhouse is surrounded with a fair amount of moisture that gets trapped and therefore, a lesser amount of watering is generally needed. Various alternatives are available for watering the greenhouse plants such as irrigation system. Irrigation can be done manually or automatically. Since manual irrigation is labor-intensive and repetitive, therefore automatic irrigation is preferable. To develop an irrigation scheduling program that provides better understanding between the plant and soil moisture relations, the necessary requirement is to accurately measure the soil water content, condition and plant size.

There are different methods available for measuring soil moisture content such as gravimetric measurement, lysimeters, neutron scattering, gamma absorption, time domain reflectometer (TDR), and also electrical resistance block. All of these methods have their own principle of operation. The summary of the techniques and their respective principles are shown in Table 1:

Table 1: Techniques of measuring soil moisture content

Method / Technique	Principle of operation for measuring soil moisture content	Advantages	Disadvantages
Gravimetric measurement	From the ratio of weight / volume of the soil	Ensure accurate measurement	Baseline measurement may lead to error
Lysimeters	From the changes in weight or drainage volume to estimate evapotranspiration	Exact determination of water balance component in soil	May cause problem to the crops in order to maintain the stability of load cells
Neutron scattering	From the ration of fast and slow neutron	Easy to use and accurate	Highly dependent on proficient calibration
Gamma absorption	From the changes in gamma attenuation	Accurate measurement below the air surface interface	Gamma rays are dangerous
TDR	From the ration of the electromagnetic pulse of energy	Convenient and reliable	Costly
Electrical resistance blocks	From meter reading of the wire lead connected to two electrodes	Inexpensive	Individually calibration for each block

Current technique that is widely used is time domain TDR. The working principle of TDR is by inserting two parallel rods or solid wires into the soil until certain depth at which the average water content is chosen. The parallel rods are attached to an instrument that sends an electromagnetic pulse or wave of energy along the rods. The rate at which the electromagnetic wave is conducted into the soil by the parallel rods and reflected back to the soil surface is directly illustrating the average water content of that particular soil. This device is convenient and reliable. However, the TDR device is expensive, costing nearly RM24,000 per unit.

Among all the techniques mentioned above, yet none of them provide clear view of the moisture percentage distribution in soil. The soil moisture status is important in effective irrigation scheduling in order to maximize profit from the production of crops. Therefore, a technique that has high accuracy to measure the moisture percentage distribution in the soil is proposed in this paper.

1.3 Objective

The objective of this study is to measure the moisture percentage distribution in the soil by using high accuracy technique. To achieve this objective, an electrical capacitance tomography will be used in order to capture the cross-sectional images of dielectric material distribution through capacitance measurement and image reconstruction. The capacitance measurements are obtained from a multi-electrode sensor. Whilst the cross-sectional distribution of the permittivity is reconstructed from these capacitance measurements. In agriculture scheme, monitoring of moisture percentage in soil is important especially during irrigation scheduling. Other than that, the moisture percentage will give benefit in the continuous monitoring of optimal irrigation scheduling in order to minimize effects of water stress on the plants.

1.4 Scope of study

The project scope can be divided into four parts whereby the first stage is the study of the theories behind tomography which specifically is electrical capacitance tomography (ECT), as well as the current technique of soil moisture detection, other techniques and also the need of controlling soil moisture mainly in agriculture sector. In order to design the ECT sensor, the author needs to do research on how the ECT sensor is being implemented. The author also needs to learn the overall operation of ECT system as well as impedance analyzer. The second stage is to design the sensor. The sensor modeling will be simulated using COMSOL Multiphysics Electromagnetic Module in order to obtain the permittivity images. Next part is the construction of the sensor. The sensor will be constructed or fabricated based on the design that the author has done in the previous part. The last part is to simulate in COMSOL and analyze data using impedance analyzer. The simulation will illustrate the image of soil moisture distribution for different volume of water added to the soil.

1.4.1 *The Relevancy of Project*

This project is relevant to the study of Physic as it focuses on the design of the ECT sensor based on determination of the dielectric permittivity distribution in the interior of an object from external capacitance measurements. Besides, monitoring of soil moisture content is important for plants in agriculture sector especially in irrigation scheduling to prevent unwanted effects such as insufficient of nutrients and plant disease due to poor irrigation planning. Monitoring of soil moisture content includes the percentage level measurement of the soil moisture. By using electrical capacitance tomography as the measurement sensor, it helps to provide the percentage of soil moisture by the capacitance measurements that are taken from the multi-electrodes sensor. The cross-sectional image of the permittivity distribution in the soil is reconstructed and the image is displayed on the computer. The continuous monitoring of soil moisture content is essential especially in improvising irrigation scheduling.

1.4.2 *Feasibility of the Project within the Scope and Time frame*

The project will be conducted starting with the collection of related materials such books, journals and technical papers specifically on current technique of soil moisture detection, Electrical Capacitance Tomography (ECT) sensor design and COMSOL application. Research will be done from time to time as to get a better understanding on the subject. This project will then focus on the modeling and simulation of the ECT sensor design using COMSOL software. Simulation will be done in order to illustrate the permittivity image of the soil moisture. Based on the activities stated above, given 4 months for the researches and studies to be done as well as experiment activities and for the other 4 months for the finalization of the design, the author feels that the project can be completed within the given time frame.

CHAPTER 2

LITERATURE REVIEW

2.1 Soil moisture content in irrigation scheduling

Optimal irrigation management is important in improving and increasing the productivity and also quality of the plants growth. Irrigation is normally used in assisting growing of the crops, maintaining the landscapes, and during the period of inadequate rain fall in certain regions. Land irrigation contributes extensively in the output of agriculture especially in food supply. Therefore accurate time and quantity of irrigation is an essential factor in developing the proficient irrigation scheduling [1].

As people know, water is very important for the plants growth. Nevertheless, if excessive amount of water is supplied to the crops, it may give negative impact to the quality and production of the plants. That is why adequate quantity of irrigation is important or otherwise the crops might end up with harmful effects due to either over irrigation or lack of water supply. Excessive irrigation will result in water logging. Too much water in the soil will affect the root growth [2]. The excessive amount of water gives no rooms or only limited space for the air. Due to this, roots cannot grow properly as too much water affects the soil aeration. Furthermore whenever the strong winds strikes, the plant roots may not be able to provide necessary anchoring in the extremely wet soil in order to protect the trees from falling onto the ground.

Besides, the process of germination is restrained because of extreme amount of water in the soil [3]. Too much water is the soil restrains the process of germination of seeds. Respiration of seeds needs both water and air. Therefore the seeds will get insufficient amount of air to perform respiration process. As a result, the seeds fail to respire and production of the crop will be affected.

Meanwhile, under irrigation or lack of water supply may also affect the plants growth. According to David, if amount of water loss exceeds the amount of water absorption, the plant might experience water stress effect. Water stress will decline the photosynthesis process and reduce the support of crop growth [4]. Hence, the quality and quantity of the growing plants will be poorly affected.

Thus, optimal and efficient irrigation scheduling is important in order to prevent all of the effects on plants growth. Either too much water or insufficient amount of water supply to the crops, both can provide negative impacts on the plants growing process. In order to manage the irrigation scheduling perfectly, the soil moisture content need to be measured adequately and monitored continuously. Therefore, an accurate and reliable technique is required for this purpose.

2.2 Soil moisture measurement

Soil moisture measurement can be determined under two criterions which are direct method and indirect method. Techniques that can be classified as direct methods are gravimetric measurement and lysimeters. Meanwhile for indirect method, there are subdivisions that can be group under this category which are radiological techniques, soil electrical permittivity, and soil electrical conductivity. Under the category of radiological techniques, there are several methods such as neutron scattering and gamma absorption. For soil electrical permittivity, soil water content can be derived from time-domain reflectometry (TDR) and electrical tomography sensor [5 - 7]. Lastly for soil electrical conductivity, methods used are electrical resistance blocks and electrical tomography sensor [8]. Each of the mentioned types of sensor will be discussed in this paper.

To make clear view of the categories, all of the methods are presented in the Figure 2 below:

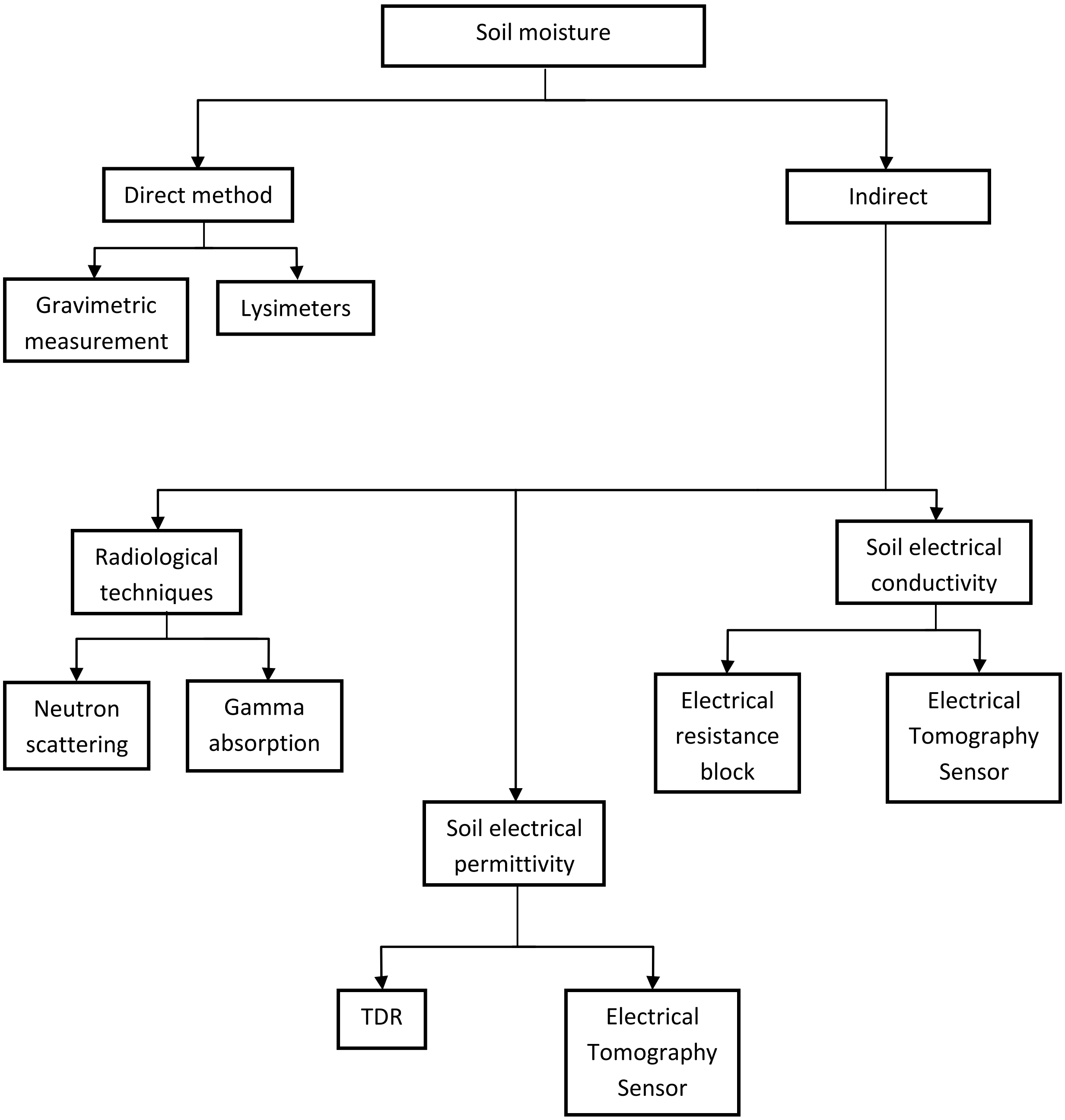


Figure 2: Classification of soil moisture detection

2.3 Gravimetric measurement

In direct method, gravimetric technique measure the soil moisture content by the weight, which is determined by the mass ratio of water present in the soil to the dry weight of the soil sample. Besides, the soil moisture content can be conveyed by the volume, which is derived from the volume ratio of water to the total volume of the soil sample [9]. In order to determine the ratio of a particular soil sample, the soil sample mass must be measured before and after the drying process.

During the drying process, the soil sample must be dried to a constant weight to determine the water mass. The water mass is the difference between the weights of the wet soil and the dry soil [10]. A dry soil sample is defined as the soil sample that has been dried in an oven for 24 hours or overnight until constant weight achieved. The drying process is operated at the range of temperature between 100℃ – 110℃, but 105℃ is a typical temperature [9]. 105℃ is chosen as a typical temperature because it is a compromise between identifying water loss and avoiding too much weight lost due to oxidation and decomposition of organic materials [11].

The procedures to obtain the soil moisture content are further explained where the drying process involves repetition [9]. The moisture content in dry weight basis, θ_d may be calculated using the following formula (1):

$$\theta_d = \frac{(weight\ of\ wet\ soil) - (weight\ of\ dry\ soil)}{weight\ of\ dry\ soil} \tag{1}$$

Once soil moisture has been measured gravimetrically, the results were compared to electronic instrumentation performances for calibration [10]. These two quantities are related by the soil bulk density. Soil bulk density is defined as the ratio of the mass of oven dry soil, M_s to the bulk volume of the soil, *V:*

$$\rho = \frac{M_s}{V} \tag{2}$$

Gravimetric soil moisture is considered by scientists as a standard for calibrating sensors. The examples are explained further on the gravimetric measurement technique [12 - 14]. This technique guarantees accurate measurement will be obtained. Nevertheless it also has some disadvantages that cannot be avoided. For instance in practice, the equation above often leads to errors. The bulk density value used is typically an average value that is determined for the soil, and the value may come from a prior study. Because of bulk density like water content is quite variable, therefore the actual bulk density of the sample may be quite different from the average value [15].

2.4 Lysimeters

The next technique in direct method is lysimeter. Lysimeter is used to maintain the sufficient soil water content for the crops. Lysimeter is a container located in the field and filled with soil that is used to maintain the vegetation for the purpose of studying different types of soil and water plant relationships under natural condition [16 - 17]. Field studies using lysimeters represent an exact tool in determining the water balance components in the soil-plant-atmosphere system [18].

The use of lysimeter is briefly explain, where from the theory, lysimeters with holes at the base which is for draining purpose are tend to generate a zone with no moisture tension in the soil above the holes [17]. However, only lysimeters which are well expanding below the root zone which is called 'shallow Lysimeters', with suction devices at their base can give the assumption and estimation of soil water content and drainage in the root zone. Moreover, evapotranspiration is one of the most significant variables in the water balance and it presents the major effects on the water loss of the system [18]. The materials and methods used to clarify the examples and experiments of lysimeters are discussed in [17 - 20].

Figure 3 below shows lysimeter cross-section:

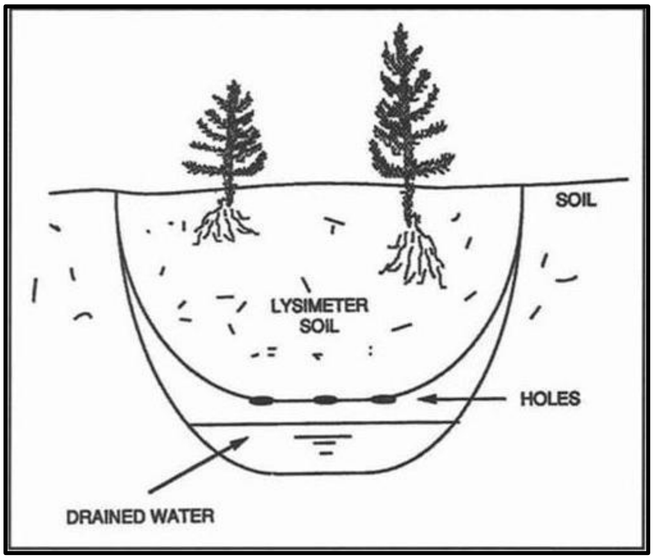


Figure 3: Lysimeter cross-section

However, the precision of weighing lysimeters is strongly depends on the quality and design of the load cells that are used to measure these changes in weight [17]. Maintaining the stability of load cells may cause problems with tree crops, especially in windy climates.

2.5 Neutron Scattering

Neutron scattering is a generally accepted non-destructive technique of soil moisture measurement [21]. According to Evett, the neutron probe uses a kind of cylindrical access tube which is usually inserted in vertical position into the soil. The access tube is used to measure for meters depth of the soil. The probe is floating inside the tube by a cable so that measurement can be made at any depth increment. Typically, the increments of depth are ranged from 10-20cm. Neutron probes are moderately accurate, user friendly, and able to take measurements in real time [22 - 24].

High-speed neutrons will be sent out by the radioactive source inside the neutron gauge or neutron probe. The size of these high-speed neutrons is quite identical with a hydrogen atom, which is one of the water molecule component. When these high-speed neutrons strike the hydrogen atoms, they will decelerate. The rate of high-speed neutrons leaving and the slow neutrons bouncing back will be measured by a probe which has a detector in it to detect the neutrons movement. The soil moisture content is approximated by the ratio [25]. Theory and methods of calibration are given by Martin, who shows that calibration against multiple volumetric soil samples that are recorded at each increment of depth.

One of the disadvantages of the neutron probes is they need to be calibrated to soil types and zones with different soil moisture fractions, over a period of time. Besides, neutron probes are also labor-intensive as the operator should wear some type of film badge. The badge will indicate the personal exposure levels to radioactive materials. The badge is then being evaluated and the level of exposure to the radioactive materials is recorded on a monthly basis [26]. Furthermore, precautions need to take into account while managing radioactive material. The materials are relatively high costs and therefore the operation of neutron probes is also costly [24]. Moreover, the probe is also inflexible to frequent and automated observations.

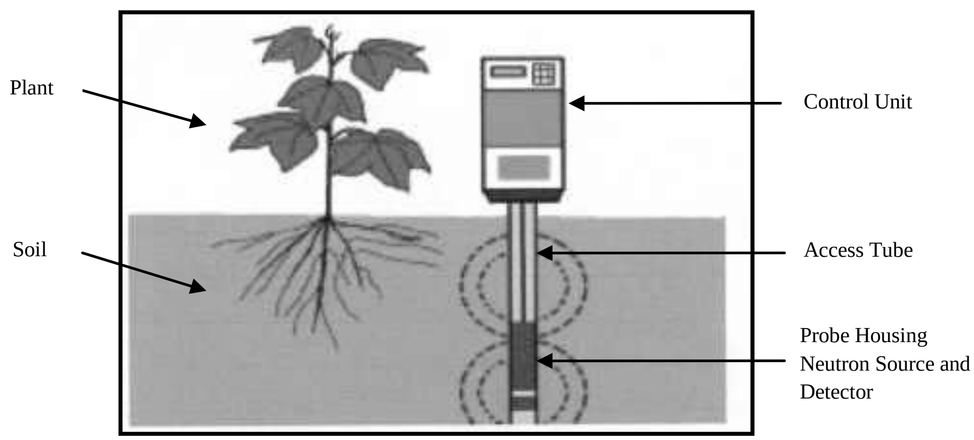


Figure 4: Diagram of a neutron moisture gauge (neutron probe)

2.6 Gamma absorption

The dual-probe gamma device is generally used in the laboratory nowadays. The reason for this is that gamma rays are more dangerous to deal with than neutron scattering devices. Furthermore, the operational costs for the gamma rays are comparatively high [27].

For a given mass absorption coefficient, changes in gamma attenuation are related to changes in total soil density. From the method judgment, the density of soil is related to the scattering and absorption of gamma rays. Since the wet density varies with the increasing or decreasing in moisture, the soil specific gravity will remain moderately constant [28]. The varies in wet density are determined by the gamma transmission method, while the moisture content will be measured from the change of density. However, it is hard to accurately measure the soil moisture content from the difference of value between the total and dry density attenuation [29].

Finally, compared to neutron scattering, gamma-ray attenuation has the advantage of allocating accurate measurements at a few centimeters below the air surface interface. Besides, it also can determine the mean of water content with depth.

2.7 Time Domain Reflectometer

The next category under indirect method is soil electrical permittivity. Under this category, there are two techniques which are time-domain reflectometer (TDR) and electrical tomography sensor. The TDR technique depends on the changes in soil permittivity that are occurred when there are variations in soil water content [30].

In the TDR method, a very quick rise time which is approximately 200ps step voltage increase will be injected into a wave guide that is usually coaxial cable. The cable will carry the wave to a probe located in the soil or other porous medium [25]. For a general field installation, the probe will be attached to the instrument through a group of coaxial cables and the multiplexers. One part of the TDR instrument supplies the voltage step and the other part which is basically a high-speed oscilloscope, will capture the reflected waveform.

The TDR technique for soil moisture measurement is a generally appropriate method that may be used for automated and manual data collection. Nevertheless, to obtain the precision and accuracy in automated measurement greatly depend on the robustness of wave form analysis methods that are being used in the software of the data logging tools. A few disadvantages of TDR which are the probes are difficult to install at depth and it is costly [31].

2.8 Electrical Resistance Blocks

Electrical resistance blocks are simple moisture measurement tools. The most common electrical resistance blocks materials are nylon fabric, fiberglass and gypsum [32]. The mechanism contains of a porous block which consists of two electrodes attached to a wire lead. The wire leads is afterward connected to a meter and reading can be taken from that meter. To retrieve the information of soil moisture from these instruments is quite difficult in clay soils. However, this device is relatively inexpensive [29].

When the electrical resistance block is covered in the soil, in order to make sure the soil and the matric potential of the block are equivalent, water will go in or out of the block until the equivalent condition occured. The more water in the soil, the lower the resistance will be. The block electrical conductivity will be interpreted using an alternating current bridge [32]. To make relationship between the electrical conductivity and the matric potential for any selective soil, a calibration curve is made.

There are a few advantages of applying electrical resistance block systems which are firstly low cost. In addition, there are chances to measure the electrical conductivity at the same point of location in that particular field for two or three years. Meanwhile the main disadvantage of this system is each block must be calibrated separately since there are some different characteristics for each blocks. Therefore, the life of the block has its own limitation since the block’s calibration varies gradually with time [31].

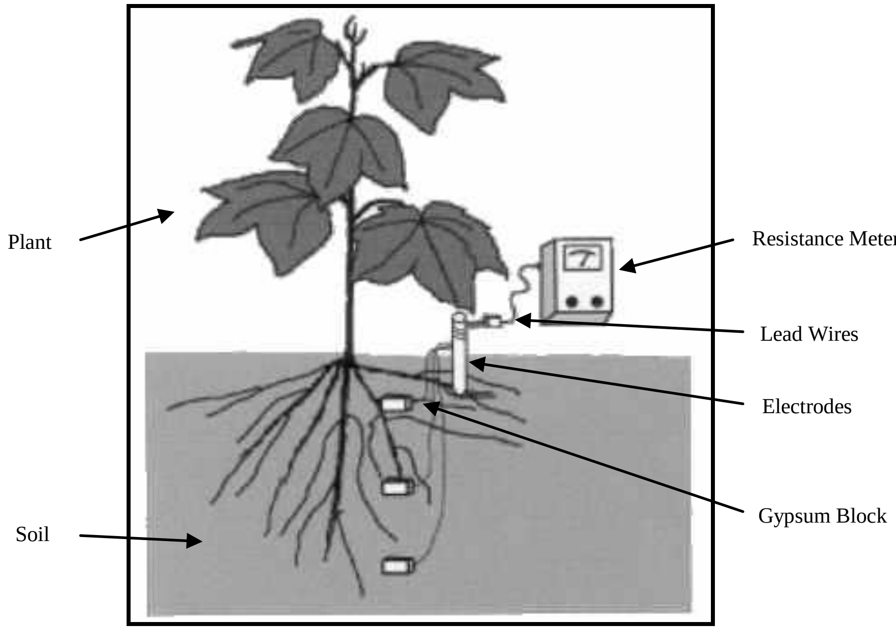


Figure 5: Diagram of electrical resistance blocks where three blocks are attached in the field

2.9 Electrical Tomography Sensor

There are many types of tomography sensors for instance optical, ionizing radiation, microwave, nuclear magnetic resonance (NMR), acoustic, and electrical (e.g., capacitive and conductive). Each technique has its own advantages and disadvantages. Hence, the preference technique is selected based on the case study. According to Ismail, a few tomographic techniques that are generally considered, which are involving the measurement of electrical properties such as electrical capacitance tomography (ECT), electrical resistance tomography (ERT), and electromagnetic tomography (EMT).

The main disadvantage of these electrical methods is their modest spatial resolution of the resultant image, because different from ionizing radiation technique where the electric fields cannot be restricted to a direct narrow path between a transmitter and a receiver. However, despite of this drawback, electrical tomography techniques has some advantages which are low-cost, non-intrusive or non-invasive, rapid response, and robustness in hostile environments [33].

From the mentioned types of tomography sensors, the one that can be used to measure soil moisture using visualization of conductivity distribution is electrical resistance tomography (ERT). ERT uses a multi-electrode array detecting soil electrical resistivity of many electrode combinations to obtain the cross-section of resistivity along the electrode array [34].

ERT is based on the injection of a controlled direct electric current (DC) through the electrodes. The electrical current flow adapts to the subsurface resistivity pattern. Therefore the potential difference or voltage at a certain distance away from the source can be determined using a second pair of electrodes. They are used to create a distribution of conductivity inside the sensor. The operation of ERT system is mainly similar as the operation of ECT system, apart from a high impedance measurement is required for conductive loads [33].

The application of ERT is shown in figure below:

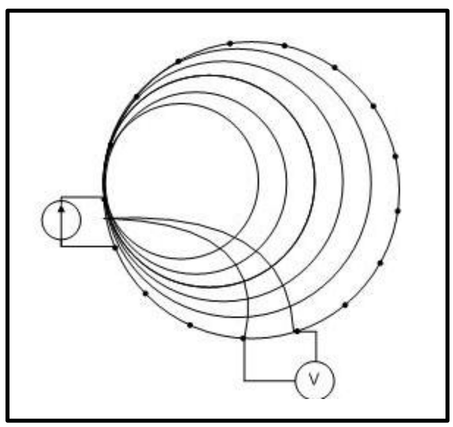


Figure 6: ERT sensor

For soil moisture measurement, electrical capacitance tomography (ECT) is one of the techniques that visualize permittivity distribution. ECT is used for imaging based on measuring the variations in capacitance which are because of the changing in dielectric material distribution. ECT presents cross-sectional images of dielectric material distribution through capacitance measurement and image reconstruction. The capacitance measurements are taken from a multi-electrode mounted around the sensor. Whilst the cross-sectional distribution of permittivity is reconstructed from these capacitance measurements. The number of electrodes used is usually 8 or 12 electrodes [35].

For parallel-plate capacitor, the relationship between capacitance and permittivity distribution is as below:

$$C = \frac{Q}{V} = \frac{1}{V} \int \int_{\Gamma} \varepsilon (x, y) \nabla \Phi (x, y) d\Gamma \qquad (3)$$

Where, $\varepsilon(x,y)$ is the permittivity distribution in the sensing field, V is the potential difference between two electrodes which form the capacitance, $\Phi(x,y)$ is the potential distribution; Γ is the electrode surface, and ∇ is the gradient operator [33].

There are three different ECT systems have been built up in the past two decades which are charge/discharge based ECT system, AC-based ECT system, and impedance analyzer based ECT system. All of these three systems have their own advantages and disadvantages. The comparison of the three systems is discussed by theoretical analysis and experiments which result in better imaging quality can be obtained by impedance analyzer compared to the two other systems [36]. However, the speed of the system is lower than the others due to low data acquisition rates of the impedance analyzer.

2.10 ECT

In this project, focus will be on tomography using ECT system. Generally, ECT is a method of measurement to gain information regarding the contents inside the pipeline or vessels. There are multiple electrodes being arranged around the edge of the pipe at permanent positions. Therefore it will not affect the movement or flow of materials inside the pipe. The multiple electrodes are placed externally for electrically insulating pipes whilst for electrically conducting pipes, the electrodes are placed internally, which means inside the pipe or vessel [37].

2.10.1 *Capacitance and permittivity*

A capacitor is a component that can store electric charge. It usually consists of two metal conductors placed near each other but not touching. A typical capacitor has a pair of parallel plates with area *A* which the plates are separated by a small distance. If a voltage (or potential) *V* is applied to a capacitor, it quickly becomes charged. The amount of charge *Q* gained by each plate is directly proportional to *V* applied, that is:

$$Q = CV \text{ or } C = \frac{Q}{V} \tag{4}$$

Where *C* is a proportionality constant called the capacitance of the capacitor. The SI unit of capacitance is coulombs per volt or farad (F), in honor of Michael Faraday.

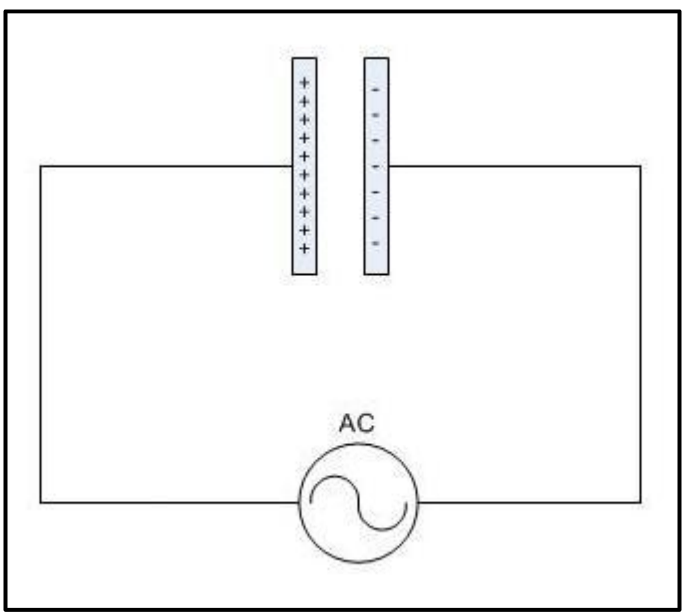


Figure 7: Charging a parallel-plate capacitor

For a parallel-plate capacitor which consists of plates with area *A* and is separated by a small distance *d* of air as shown in Figure 4, the capacitance is also proportional to *A* and inversely proportional to *d.* An alternative expression for the capacitance is then:

$$C = \varepsilon_0 \frac{A}{d} \tag{5}$$

where *A* is the cross-sectional area of the capacitor and *d* the distance between the plates. The proportionality constant is found to have the value ε_0, the permittivity of free space as shown in Figure 8:

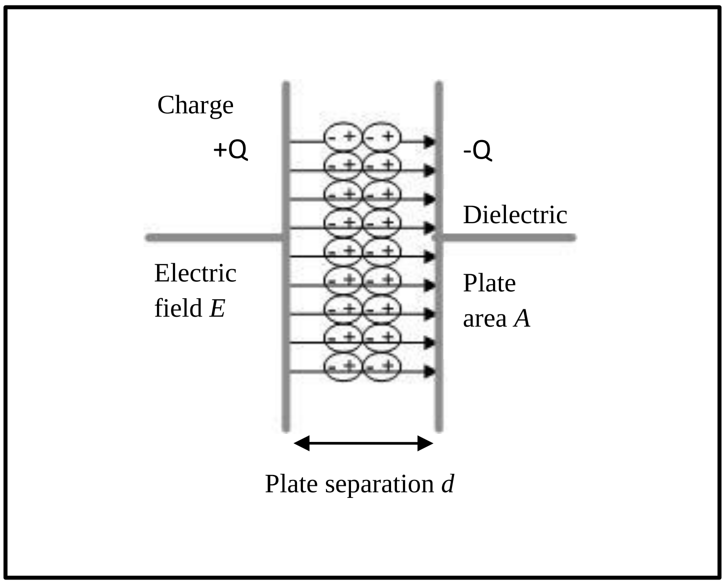


Figure 8: Electric charge and voltage of capacitor

The capacitance for a parallel plate capacitor with dielectric between the plates is therefore given by where ε is called the permittivity of the material. κ is known as dielectric constant, a factor indicating by how many fold capacitance is increased.

$$C = k\varepsilon_0 \frac{A}{d} = \varepsilon \frac{A}{d} \tag{6}$$

The ECT concept generally can be described as it is derived from the capacitance as well as the permittivity of the material inside the pipe or process vessel. Since the permittivity of each measured element is a constant, the measured element can be identified by knowing the capacitance / voltage between electrodes.

2.11 Impedance analyzer based ECT system

A commercial impedance analyzer which is considered as a high sensitivity ECT system is used for capacitance measurement. Impedance analyzer can measure sensitivity of 10 times higher than conventional ECT systems [38]. Impedance analyzer is intended for common impedance measurement and can be used in many diverse applications such as in medical application, process monitoring, and also non destructive testing [39 – 40]. It also conveys reliable and outstanding performance for accuracy and resolution.

The main disadvantage of impedance analyzer is it has low acquisition rate and has limited number of channels for measurement. Besides, impedance analyzers are also bulky in size. Generally, when different sensor electrodes are used to take measurements, the terminal connections of the multi electrodes sensor have to be changed manually [41].

The impedance analyzer ECT system consists of electrical capacitance tomography sensor, an impedance analyzer (i.e. HP4284A), a host PC, and also the terminal connections. Therefore in order to develop the flexibility in multi electrodes sensor connection between the terminals, a multiplexer (MUX) unit can be established to enable the impedance measurement between the sensor electrodes and the impedance analyzer. The multiplexer are designed to make sure minimum stray of capacitance [42].

The MUX unit is controlled by a data acquisition board and two data acquisition units. The connection from the impedance analyzer to the PC is by the standard HP-IB instrument communication protocol. To allow the connection and communication between these two devices, an IEEE488 card from Brainbox is installed to the host PC [42].

For example, if 12 electrodes sensor is used, electrode 4 is used for the excitation whereas electrodes 5-12 for detection thus, eight capacitance measurements can be obtained. Next, electrode 5 will be used as excitation and electrodes 6-12 for detection. With that, seven measurements of capacitance are gained. The method will continue until electrode 11 is used for excitation and electrode 12 for detection and only one capacitance measurement is obtained. Therefore, a 12 electrodes ECT sensor will give 66 independent measurements of electrode pairs, which is designated in Table 1.

Table 2: Measurement of 12 electrodes ECT sensor

Electrodes	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}
2			C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}	C_{20}	C_{21}
3				C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	C_{28}	C_{29}	C_{30}
4					C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{36}	C_{37}	C_{38}
5						C_{39}	C_{40}	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}
6							C_{46}	C_{47}	C_{48}	C_{49}	C_{50}	C_{51}
7								C_{52}	C_{53}	C_{54}	C_{55}	C_{56}
8									C_{57}	C_{58}	C_{59}	C_{60}
9										C_{61}	C_{62}	C_{63}
10											C_{64}	C_{65}
11												C_{66}
12												

2.12.1 *Number of Electrodes*

ECT sensor may consists of 8, 12 or 16 numbers of electrodes. In choosing the electrode numbers, normally, 8 or 12 electrodes will be used for ECT sensors. Designers usually use large number of electrodes in order to have better image resolution of the ECT. When more number of electrodes being used, it means more numbers of independent measurement will be produced. Big electrode numbers are necessary to perform a high sensitivity measurement. At the processing unit, large numbers of data will be generated if more numbers of electrodes are used in designing the ECT sensor [35]. Nevertheless, there are a some advantages of using less number of electrodes. First of all, the hardware design will be much simpler which will cause lesser number of data acquisition required to present the data. Moreover, it will provide quicker data acquisition rate since the number of capacitance measurements have been reduced [43].

2.12.2 *Electrodes size*

There is possibility to measure the capacitance by using the capacitance measuring circuit. For the length of the measurement electrodes, typically it is the same as the sensor diameter, if the diameter of the sensor is large enough for example 10cm [43]. Furthermore, while choosing the length of electrodes, it is also significant to consider the 3D effect. To avoid severe effect to both axial ends of the ECT sensor, generally the electrodes length are greater than diameter of the sensor.

2.12.3 *Electrodes position*

The measurement electrodes are usually placed outside of the sensor or any insulating frame that act as sensor. The sensor design can be classify into two types which are invasive and non-invasive. ECT sensor is said to be non-intrusive and non-invasive, therefore the electrodes are placed at the outer part of the sensor because it has no direct contact with the measurement area. But if the sensor is placed internally, it is called non-intrusive and invasive [43].

2.12.4 *Earthed screens*

There are three types of earthed screens that are being used in ECT sensor which are outer screen, two axial end screens and radial screens [43]. Generally, the type of earthed screen that is normally used are two earthed axial end screens which able to lessen the external noise to some extent. Besides, since the electric field is dragged to the earthed axial end screens, it have negative effect on the capacitance measurement. The earthed radial end screens are used mainly to decrease the standing capacitance between any adjacent electrode pairs of the ECT sensor.

2.13 Image Construction

To get information regarding distribution of the dielectric material inside a closed pipe in ECT, electrical capacitance is measured between sets of electrodes that are placed outside the sensor. Then the measured data is sent to data acquisition unit for processing. After that, the electrical capacitance is then being converted into an image to present the distribution of the permittivity and the material using an appropriate algorithm [44].

There are several types of measurement method but commonly used method is normal adjacent. When voltage is supplied through an electrode, and then the permittivity between the that particular electrode and other electrodes are being measured [35]. For example of using 12 electrodes ECT sensor, when the first electrode is initialized, the voltage between first and second electrode is measured. This 1-2 voltage measurement continued with 1-3, 1-4, …, and 1-12 voltage measurements. After completing 2-3, 2-4, 2-5, …, until 11-12 voltage measurement, it is considered as one set of data.

Later on, those procedures will be repeated by initializing other numbers of electrodes. Therefore for n number of electrodes, n(n-1)/2 measurements will be taken. Hence, 66 independent measurements can be obtain from a 12-electrodes ECT sensor as listed in Table 2.

There are two categories for image reconstruction algorithms in ECT which are non-iterative algorithms and iterative algorithms. Among all non-iterative algorithms, the fastest and the simplest algorithm is Linear Back Projection (LBP) [44]. LBP is compatible for high-speed dynamic processes. Furthermore, it is commonly used in on-line image reconstruction. However, LBP also has some restrictions regarding resolution and accuracy.

For instance, according to Xie *et al*., (1992), the LBP has been developed to reconstruct images using 12-electrodes sensor of ECT. Thus the correlation between distribution of permittivity and capacitance can be estimated and expressed in a linear form as:

$$B = S.X \tag{8}$$

where *B* is the matrix of normalized capacitance, *S* is the matrix of transducer sensitivity (normalized capacitance relating to normalized permittivity), and *X* is the matrix of pixel gray level (which is the normalized permittivity). In ECT image reconstruction, it is mainly to resolve the permittivity distribution of the material inside the pipe from the measured capacitance obtained. In the separate means, the task is to find the unknown *X* from the known *B*, whilst *S* is a constant matrix for straightforwardness. It can be conclude that LBP is generally to calculate the pixel gray level by using the transpose of the sensitivity matrix as a replacement for its inverse [44].

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

In order to achieve the aim of the project, some researches had been done on several resources from books, technical papers and internet. For the first step, the author did literature review by gathering some information on the soil moisture detection, control of soil moisture, and electrical capacitance tomography (ECT) on how to design sensor. Based on this research, the author will come out with a fine ECT sensor.

After all the studies have been done, the next stage is to fabricate the ECT sensor where the sensor will illustrate the data of the soil moisture content in the pipe. For data acquisition, the instrument used is the impedance analyzer. It has measurement sensitivity ten times higher than the conventional ECT system. The design of the ECT sensor is done by considering the number of electrodes, earthed screen, and length of electrodes. The design sensor need to be checked whether it meets the ECT sensor requirements or not.

Next, the intended low and high calibration will be conducted using the impedance analyzer in laboratory. Dry soil is used for low calibration while moist soil is used for high calibration. To begin the experiment, the sensor will be put inside a basin or container and the soil will be place in the pipe afterwards, starting with the dry soil. Then amount of water will be added to the pipe for 10ml, 20ml, 30m, …, and 400ml accordingly in order to obtain the results and data of the soil moisture. Several tests will be conducted on ECT sensor with different types of soil by following the test procedure.

3.2 Project Identification

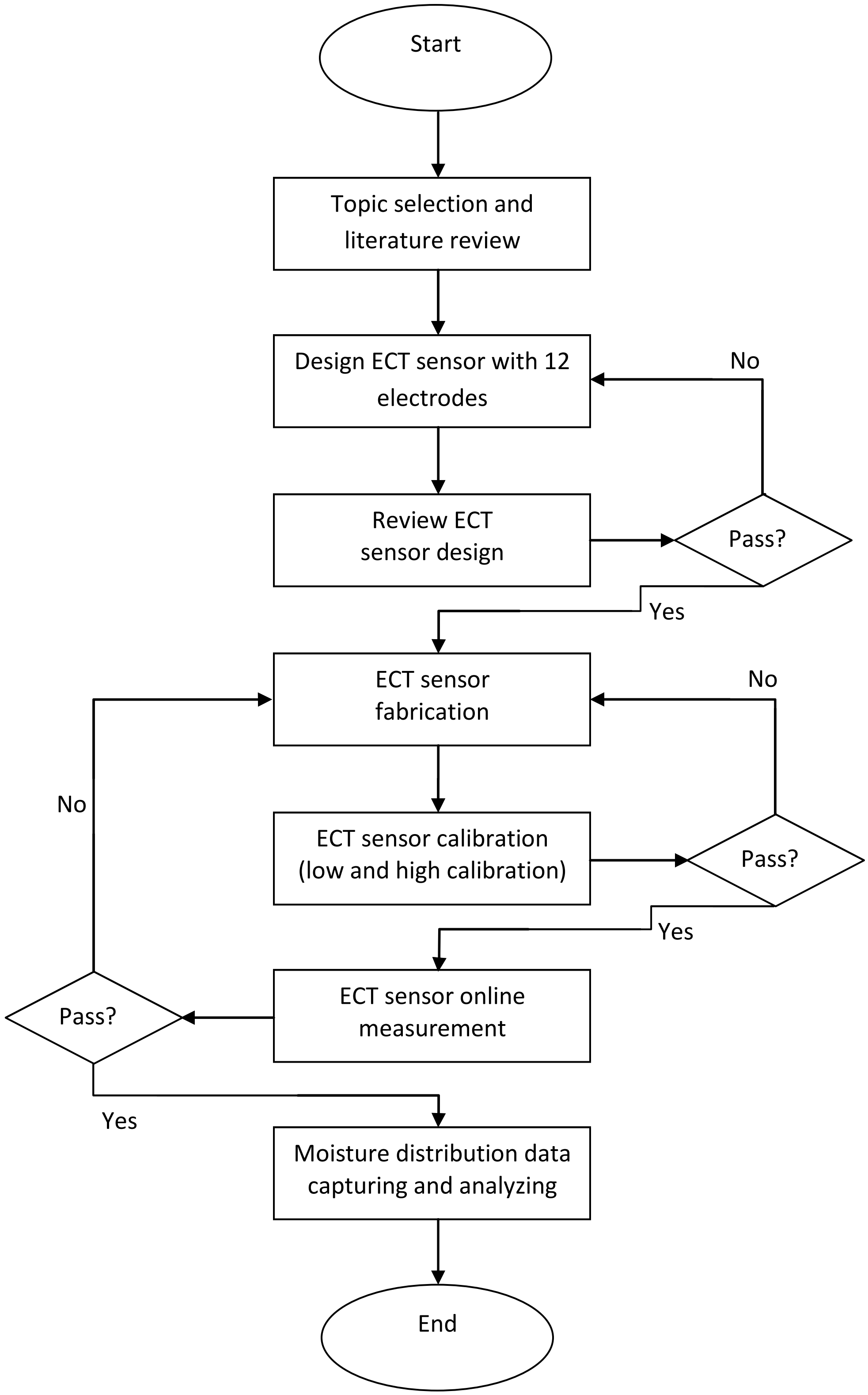


Figure 11: Flow chart for project identification

3.3 ECT Sensor Design Criteria

There are few features in order to design the ECT sensor for pipeline. A pipeline ECT sensor consists of a set of measurement electrodes placed outside or inside an insulating pipe with similar distance of electrodes. These sensors can be categorized into four groups according to their physical structure as shown in Table 2:

(i) Type 1: External electrodes with radial screens.

(ii) Type 2: Internal electrodes without radial screens.

(iii) Type 3: External electrodes without radial screens.

(iv) Type 4: Internal electrodes with radial screens.

Table 3: Features of the four types of ECT Sensor

Group	**1**	**2**	**3**	**4**
Electrode Position	External	Internal	External	Internal
Radial Screen	Yes	No	No	Yes
Advantages	Small standing capacitance, no contact to process	High sensitivity, easy to construct	Simple, low cost, easy to construct, no contact to process	Small standing capacitance, no pipe wall capacitance effect, high sensitivity
Disadvantages	Has pipe wall capacitance effect, difficult to construct	Electrostatic pick up, pipe wall capacitive effect, contact to process	Large standing capacitance, pipe wall capacitance effect	Electrostatic pick up, difficult to prevent leakage, difficult to construct
Applications	Oil pipeline measurement, fluidized bed analysis, water hammer monitoring	Flame detection, fluidized bed analysis, oil/gas/water flow measurement	Pneumatic conveyor measurement, trickle bed monitoring	Flame detection

In order to design the best sensor for the project, the author needs to calculate the measurements of the width and length of the electrode. The author also has to precise the measurements so that the parts and pieces can be assembled as planned. Initially, the author plan to use type 3 for ECT sensor due to the advantages of it as it is simple and also easy to construct. The details of the sensor are as in Table 3:

Table 4: ECT Sensor information

ECT sensor	**Specification**
Number of electrodes	12
Length of electrode	10 cm
Width of electrode	1.0 cm
Space between electrodes	0.6 cm
Diameter of pipe	6.0cm
Material (electrodes)	Copper

3.4 Experimental Procedures

- Oven dry

The weight of the weight soil will be measured before the drying process. The sample of soil will be dried in a microwave oven for 24 hours with 105℃ temperature to ensure that the soil is totally dry. After that the weight of the dry soil will be measured. The soil moisture percentage will be calculated using oven dry method equation as reference value. This technique is called gravimetric method.

- Impedance Analyzer and ECT

For the intended calibration, low and high calibration will be done. For low calibration, the dry soil will be placed in the ECT sensor and data will be analyzed. After that, the high calibration process will be done by adding amount of 400ml water into the dry soil inside the ECT sensor. Then data will be captured. The experiment will begin by inserting dry soil into ECT sensor and amount of water will be added for 50ml, 100ml, 150ml, …, and 400ml accordingly. The data will be captured for time interval of 10 seconds for every measurement.

- Measurement of soil moisture content

The measurement of soil moisture content will be calculated by using the capacitance value, following this equation:

$$\theta = \frac{C_m - C_l}{C_h - C_l} \qquad (9)$$

The percentage of soil moisture calculated from the capacitance value is then being compared to the soil moisture percentage gained from oven dry method to see the correlation between those two techniques.

3.5 Tools Required

For the accomplishment of the project, there are needs for a certain software application especially for modeling and simulation process for the design. For this project, the modeling and simulation will be done using COMSOL software and impedance analyzer. For sensor fabrication and calibration, the tools listed in Table 5 are used:

Table 5: Tools for sensor fabrication and calibration

No.	Tools	Description
1.	Data cable	Provides connection from ECT sensor to ITS device
2.	Polyvinyl chloride pipe (PVC)	Act as body of the sensor
3.	Copper tape	Sensing material that allows electric potential to flow through it.
4.	Impedance Analyzer	Data processing and analyzing

Result shows that when applying shielding to the ECT sensor, the capacitance result will be more stable as the shielding purpose is to minimize the noise that might disturb the measurement of capacitance.

4.3 Experiment

The experiment is firstly done by using the oven dry method which is used as reference for the soil moisture content calculation. The soil is dried in th oven for more than 24 hours before starting the experiment to have a totally dried soil. The result from the oven dry method is as shown below.

Mass of container, M_c : 166g

Mass of dry soil + Mass of container: 395.65g

Mass of dry soil, M_d : 395.65g – 166g = 229.65g

Mass of wet soil, M_w :

Quantity of water	$M_c + M_w$	M_w	Moisture percentage (%)
50ml	441.97g	275.97g	12.3
100ml	488.97g	322.97g	24.8
150ml	536.80g	370.80g	37.5
200ml	584.24g	418.24g	50.0
250ml	631.33g	465.33g	62.5
300ml	678.74g	512.74g	75.1
350ml	725.60g	559.60g	87.6
400ml	772.48g	606.48g	100.0

The capacitance value for each group as increasing water content are as follow:

Adjacent

	e1-2	e2-3	e3-4	e4-5	e5-6	e6-7
0ml	2.60992	2.5776	2.72028	2.68357	2.6796	2.501826
50ml	2.700905	2.703401	2.827307	2.901462	3.044945	2.86021
100ml	2.769799	2.8013618	2.948477	2.997993	3.093216	2.90351
150ml	2.9912	2.92225	2.99635	3.09337	3.12523	3.088577
200ml	3.128183	3.0045127	3.073797	3.125946	3.156328	3.140441
250ml	3.205463	3.1574553	3.193235	3.154211	3.189214	3.208593
300ml	3.259235	3.2574019	3.23037	3.23409	3.249473	3.26454
350ml	3.31561	3.2928732	3.314986	3.308192	3.292877	3.297571
400ml	3.383915	3.3321261	3.390229	3.384428	3.35556	3.377789

	e7-8	e8-9	e9-10	e10-11	e11-12	e1-12	Average
0ml	2.56767	2.33601	2.476315	2.53854	2.436832	2.48481	**2.551081**
50ml	2.804809	2.467835	2.5371	2.777893	2.54618	2.507881	**2.723327**
100ml	2.84077	2.765374	2.710455	2.969971	2.679603	2.578872	**2.838283**
150ml	2.974193	2.8717	2.84368	3.03241	2.90442	2.80158	**2.970413**
200ml	3.068843	2.934205	2.927124	3.100701	3.141541	2.976339	**3.06483**
250ml	3.122997	3.104378	3.10167	3.160727	3.191555	3.171179	**3.16339**
300ml	3.244102	3.197571	3.12085	3.24692	3.265308	3.213425	**3.231941**
350ml	3.317014	3.287327	3.206311	3.276518	3.297928	3.29814	**3.292112**
400ml	3.39988	3.33746	3.282397	3.359705	3.355531	3.365067	**3.360341**

1-adjacent

	e1-3	e2-4	e3-5	e4-6	e5-7	e6-8
low	0.969999	0.990015	0.978468	0.986993	1.01186	0.983281
50ml	1.593225	1.492422	1.484963	1.539466	1.540486	1.474731
100ml	1.724485	1.657195	1.686249	1.698428	1.722138	1.683192
150ml	1.812879	1.786892	1.75962	1.800662	1.85773	1.83455
200ml	2.028403	2.004954	1.958117	2.041553	2.049319	2.017932
350ml	2.276868	2.249319	2.176901	2.23347	2.26804	2.194433
300ml	2.457195	2.484963	2.427256	2.478767	2.495017	2.421054
350ml	2.658117	2.55962	2.540088	2.654892	2.670918	2.593298
400ml	2.830324	2.822138	2.745959	2.8353	2.851032	2.810937

	e7-9	e8-10	e9-11	e10-12	e1-11	e2-12	Average
low	0.933082	0.944741	0.981509	1.003	0.956792	0.944294	**0.97367**
50ml	1.437806	1.453683	1.485767	1.527761	1.475361	1.419607	**1.493773**
100ml	1.676868	1.691352	1.712879	1.73418	1.686892	1.644954	**1.693234**
150ml	1.71568	1.7521	1.82755	1.84544	1.83515	1.81313	**1.803449**
200ml	1.918146	1.995376	2.074232	2.053709	2.0298	2.001033	**2.014381**
350ml	2.190679	2.249189	2.244197	2.247255	2.208301	2.195579	**2.227853**
300ml	2.430324	2.472914	2.466028	2.459686	2.404212	2.371998	**2.447451**
350ml	2.604938	2.647277	2.63818	2.637881	2.578409	2.548529	**2.611012**
400ml	2.809748	2.795496	2.793225	2.724485	2.728403	2.7979	**2.795412**

2-adjacent

	e1-4	e2-5	e3-6	e4-7	e5-8	e6-9
low	0.885085	0.876262	0.89628	0.90137	0.91236	0.85703
50ml	1.2389	1.108172	1.1563	1.20977	1.23927	1.18455
100ml	1.473812	1.426495	1.46117	1.48759	1.51348	1.43641
150ml	1.60738	1.58515	1.59918	1.62499	1.65128	1.57651
200ml	1.829037	1.814255	1.83581	1.84258	1.87172	1.79128
350ml	2.014706	2.011284	2.09202	2.18232	2.08177	2.02088
300ml	2.31651	2.234552	2.30368	2.28805	2.28759	2.22666
350ml	2.426495	2.419935	2.46216	2.47964	2.47905	2.41817
400ml	2.622976	2.620438	2.65225	2.65302	2.64944	2.62897

	e7-10	e8-11	e9-12	e1-10	e2-11	e3-12	Average
low	0.86069	0.86348	0.89786	0.869882	0.86166	0.85722	**0.878264**
50ml	1.26473	1.21471	1.25367	1.191909	1.19202	1.17448	**1.202373**
100ml	1.46769	1.44934	1.42264	1.390305	1.39808	1.42761	**1.446217**
150ml	1.62642	1.60077	1.63368	1.54485	1.63896	1.61843	**1.608967**
200ml	1.81531	1.87724	1.88698	1.819935	1.87265	1.76216	**1.834912**
350ml	2.12211	2.06705	2.09699	1.998821	2.02871	2.09013	**2.067233**
300ml	2.32771	2.32682	2.28713	2.267995	2.22763	2.25808	**2.279368**
350ml	2.4195	2.41837	2.47847	2.462163	2.40564	2.39665	**2.438854**
400ml	2.57506	2.61938	2.67847	2.619864	2.62686	2.6394	**2.632178**

3-adjacent

	e1-5	e2-6	e3-7	e4-8	e5-9	e6-10
low	0.859492	0.876262	0.876224	0.879825	0.83789	0.840241
50ml	1.13874	1.158172	1.147164	1.132856	1.168308	1.17401
100ml	1.244757	1.226495	1.257271	1.234557	1.236883	1.241966
150ml	1.42799	1.48515	1.45053	1.473	1.46145	1.46837
200ml	1.609711	1.622168	1.630354	1.632893	1.678548	1.627117
350ml	1.819061	1.819709	1.819792	1.819592	1.818068	1.818957
300ml	2.025127	2.025675	2.025745	2.025576	2.024288	2.025039
350ml	2.216227	2.216922	2.217011	2.216797	2.215163	2.216116
400ml	2.419802	2.420438	2.42052	2.417441	2.402547	2.45636

	e7-11	e8-12	e1-9	e2-10	e3-11	e4-12	Average
low	0.838468	0.843915	0.846303	0.841808	0.839103	0.838189	**0.851477**
50ml	1.129292	1.142193	1.154262	1.124398	1.147866	1.131633	**1.145741**
100ml	1.298322	1.258903	1.265037	1.281579	1.255276	1.216083	**1.251427**
150ml	1.44852	1.456	1.42286	1.42254	1.35673	1.38292	**1.438005**
200ml	1.603415	1.608669	1.562868	1.609419	1.578387	1.653826	**1.618115**
350ml	1.828584	1.767701	1.818615	1.819371	1.798134	1.817531	**1.81376**
300ml	2.024831	2.043574	2.02475	2.025389	2.024786	2.024632	**2.026618**
350ml	2.215852	2.215251	2.215749	2.21656	2.215794	2.2156	**2.216087**
400ml	2.435042	2.429706	2.465502	2.418435	2.406219	2.42661	**2.426552**

4-adjacent

	e1-6	e2-7	e3-8	e4-9	e5-10	e6-11
low	0.853261	0.867662	0.868147	0.831007	0.833264	0.831081
50ml	1.128	1.137695	1.147204	1.139215	1.169391	1.135346
100ml	1.366783	1.428656	1.358541	1.334516	1.308924	1.282546
150ml	1.51389	1.5259	1.52487	1.48324	1.43457	1.42121
200ml	1.710882	1.725924	1.724598	1.748698	1.71513	1.70913
350ml	1.917855	1.918667	1.918028	1.91703	1.917548	1.902158
300ml	2.124107	2.124794	2.124254	2.12341	2.123848	2.123544
350ml	2.214934	2.215805	2.21512	2.21405	2.214605	2.21422
400ml	2.318618	2.319415	2.347154	2.345016	2.335801	2.368512

	e7-12	e1-8	e2-9	e3-10	e4-11	e5-12	Average
low	0.83082	0.851116	0.831604	0.832723	0.831977	0.830484	**0.841096**
50ml	1.12119	1.151535	1.098078	1.129597	1.10153	1.143226	**1.133501**
100ml	1.333052	1.296669	1.290106	1.283764	1.271819	1.296955	**1.321027**
150ml	1.52338	1.51622	1.49652	1.45845	1.55875	1.51614	**1.497762**
200ml	1.742759	1.725796	1.75708	1.693085	1.758099	1.765356	**1.731378**
350ml	1.935889	1.917618	1.917183	1.917635	1.907353	1.937199	**1.91868**
300ml	2.123525	2.123907	2.123539	2.123921	2.123761	2.123294	**2.123825**
350ml	2.214196	2.21468	2.214213	2.214698	2.214495	2.213903	**2.214577**
400ml	2.31555	2.324052	2.340228	2.353218	2.386804	2.370305	**2.343723**

Opposite

	e1-7	e2-8	e3-9	e4-10	e5-11	e6-12	Average
low	0.850258	0.864976	0.828451	0.831566	0.829477	0.828302	**0.838838**
50ml	1.085606	1.063199	1.0031	1.048633	1.018292	1.024967	**1.040633**
100ml	1.274038	1.224801	1.164959	1.221056	1.157595	1.220672	**1.21052**
150ml	1.40382	1.34838	1.25488	1.37322	1.30659	1.31428	**1.333528**
200ml	1.567348	1.531923	1.444877	1.495142	1.48313	1.465466	**1.497981**
350ml	1.717692	1.717827	1.616494	1.617385	1.680578	1.599025	**1.658167**
300ml	1.923969	1.924084	1.822957	1.82371	1.823193	1.822998	**1.856818**
350ml	2.114759	2.114904	2.013475	2.11443	2.013774	2.013528	**2.064145**
400ml	2.318458	2.326104	2.273274	2.27522	2.348632	2.305275	**2.307827**

Table 9: Moisture percentage for one after adjacent electrodes

Water added in soil (ml)	Moisture content - oven dry (%)	Moisture content – ECT (1-adjacent) (%)	Percentage difference (%)
50	12.30	28.57	16.27
100	24.80	39.56	14.76
150	37.50	45.60	8.1
200	50.00	57.14	7.14
250	62.50	68.68	6.18
300	75.10	80.77	5.67
350	87.60	90.11	2.51

Table 10: Moisture percentage for two after adjacent electrodes

Water added in soil (ml)	Moisture content - oven dry (%)	Moisture content – ECT (2-adjacent) (%)	Percentage difference (%)
50	12.30	18.75	6.45
100	24.80	32.39	7.59
150	37.50	41.47	3.97
200	50.00	54.55	4.55
250	62.50	67.61	5.11
300	75.10	79.54	4.44
350	87.60	88.63	1.03

Table 11: Moisture percentage for three after adjacent electrodes

Water added in soil (ml)	Moisture content - oven dry (%)	Moisture content – ECT (3-adjacent) (%)	Percentage difference (%)
50	12.30	18.47	6.17
100	24.80	25.48	0.68
150	37.50	36.94	0.56
200	50.00	48.40	1.60
250	62.50	61.15	1.35
300	75.10	74.52	0.58
350	87.60	86.62	0.98

Table 12: Moisture percentage for four after adjacent electrodes

Water added in soil (ml)	Moisture content - oven dry (%)	Moisture content – ECT (4-adjacent) (%)	Percentage difference (%)
50	12.30	19.33	7.03
100	24.80	32.00	7.20
150	37.50	43.33	5.83
200	50.00	59.33	9.33
250	62.50	72.79	10.29
300	75.10	85.33	10.23
350	87.60	91.33	3.73

Table 13: Moisture percentage for opposite electrodes

Water added in soil (ml)	Moisture content - oven dry (%)	Moisture content – ECT (opposite) (%)	Percentage difference (%)
50	12.30	13.61	1.31
100	24.80	25.17	0.37
150	37.50	33.33	4.17
200	50.00	44.90	5.10
250	62.50	55.78	6.72
300	75.10	69.39	5.71
350	87.60	82.99	4.61

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The experimental works will be performed to illustrate the soil moisture content by using electrical capacitance sensor. By developing this method using impedance analyzer and ECT, the clear view of moisture percentage distribution in soil can be obtained by using high accuracy technique especially for the irrigation system in greenhouse. Most greenhouse vegetable plants remove large amounts of water from soil at approximately 10" to 12" depth. An accurate estimate of available soil moisture at this depth cannot be made by testing only the top few inches of soil.

The sensor is designed by using twelve external electrodes. By using electrical capacitance tomography, the cross-sectional images of dielectric material distribution can be captured through capacitance measurement and image reconstruction. Monitoring of moisture percentage in soil is important in agriculture scheme, especially during irrigation scheduling. Besides, the moisture percentage will give advantage in the continuous monitoring of optimal irrigation scheduling in order to minimize effects of water stress on the plants.

5.2 Recommendations

There is more improvements need to be done in order to obtain the desired and excellent results. The improvements that can be made in continuing the project is by designing the sensor that is in square shape to paste two plates on it. The area of the electrodes also need to be increase while the distance will be decreased. Besides, the sensor also need to install shielding around it. Thus, it will shield the sensor system from the ambient systems and prevent charge disturbances on the electrodes due to external changed objects.

In continuing this project, the author will do more studies on the soil moisture content calculation from the data obtained by using the impedance analyzer. These have to be achieved in order to prove that the sensor is reliable for the soil moisture detection. Besides, the experiment will be conducted with homogeneity in order for the sensor to detect the soil moisture content at any point with almost close result.

Other than that, the author will continue the project by performing the experiment with both types of sensor which is twelve electrodes sensor and two parallel plates capacitance sensor. the two parallel plates sensor will be connected to impedance analyzer to analyze the data while the 12 electrodes sensor will be connected to tomography system. The data is then being compared to select the most reliable and effective sensor, with simpler fabrication thus less cost required.

REFERENCE

[1] S. M. Sezen, G. Celikel, A. Yazar, S. Tekin, and B. Kapur, “Effect of Irrigation Management on Yield and Quality of Tomatoes Grown in Different Soilless Media in a Glasshouse”, *Scientific Research and Essay, Academic Journals*, vol. 5, pp. 41 – 48, January 2010.

[2] M. J. Puma and B. I. Cook, “Effects of Irrigation on Global Climate during the 20th Century”, *Journal of Geophysical Research*, vol. 115, pp. 1 – 15, August 2010.

[3] Y. Zhang, E. Kendy, Y. Qiang, L. Changming, S. Yanjun, and S. H. Yong, “Effect of Soil Water Deficit on Evapotranspiration, Crop Yield, and Water Use Efficiency in the North China Plain’, *Agricultural and Water Management Journal*, vol. 62, pp. 107 – 122, January 2004.

[4] T. P. David, “Effects of Environmental Stress on Weed or Crop Interactions*”, Weed Science Journal*, vol. 43, pp. 483 – 490, September 1995.

[5] K. W. Weiler, T. S. Steenhuis, J. Boll, and K. J. S. Kung, “Comparison of Ground Penetrating Radar and Time-Domain Reflectometry as Soil Water Sensors”, *Soil Science Society of America Journal*, vol. 62, pp. 1237 – 1239, 1998.

[6] M. Sun, W. Maichen, R. Pophale, Y. Liu, R. Cai, C. M. Lew, H. Hunt, M. W. Deem, M. E. Davis, and Y. Yan, “Dielectric Constant Measurement of Zeolite Powders by Time-Domain Reflectometry”, *Microporous and Mesoporous Materials*, vol. 123, pp. 10 – 14, March 2009.

[7] C. Rudiger, A. W. Western, J. P. Walker, A. B. Smith, J. D. Kalma, and G. R. Willgoose, “Towards a General Equation for Frequency Domain Reflectometers”, *Journal of Hydrology*, vol. 383, pp. 319 – 329, 2010.

[8] J. H. Knight, “Sensitivity of Time Domain Reflectometry Measurements to Lateral Variations in Soil Water Content”, *Water Resources Research*, vol. 28, pp. 2345 – 2352, 1992.

[9] K. M. Deangelis, “Measurement of Soil Moisture Content by Gravimetric Method”, *American Society of Agronomy, Madison, Wisconsin, USA*, pp. 1 – 2, January 2007.

[10] V. Francesca, F. Osvaldo, P. Stefano, and R. P. Paola, “Soil Moisture Measurements: Comparison of Instrumentation Performances”, *Journal of Irrigation and Drainage Engineering*, vol. 136, no. 2, pp. 81 – 89, February 2010.

[11] D. A. Robinson, C. S. Campbell, J. W. Hopmans, B. K. Hornbuckle, S. B. Jones, R. Knight, F. Ogden, J. Selker, and O. Wendroth, “Soil Moisture Measurement for Ecological and Hydrological Watershed-Scale Observatories: A Review*”, Soil Science Society of America Journal*, vol. 7, no. 1, pp. 358 – 389, February 2008.

[12] J. P. Walker, G. R. Willgoose, and J. D. Kalma, "In Situ Measurement of Soil Moisture: A comparison of Techniques", *Journal of Hydrology*, vol. 293, pp. 85 – 99, January 2004.

[13] O. Merlin, J. P. Walker, R. Panciera, R. Young, J. D. Kalma, and E. J. Kim, "Soil Moisture Measurement in Heterogeneous Terrain", *Int. Congress on Modelling and Simulation*, Modelling and Simulation Society of Australia and New Zealand, pp. 2604 – 2610, 2007.

[14] M. S. Seyfried, and M. D. Murdock, "Measurement of Soil Water Content with a 50-MHz Soil Dielectric Sensor" *Soil Science Society of America Journal*, vol. 68, pp. 394 – 403, 2004.

[15] P. Cepuder, S. R. Evett, L. K. Heng, C. Hignett, J. P. Laurent, and P. Ruelle, "Field Estimation of Soil Water Content: A Practical Guide to Methods, Instrumentation and Sensor Technology", International Atomic Energy Agency, Vienna, Austria, vol. 30, February 2008.

[16] J. C. David, P. K. Andrews, K. M. Harris, E. A. Cameron, and H. W. Caspari, "Performance of Drainage Lysimeters for the Evaluation of Water Use by Asian Pears", *Hort Science Journal*, vol. 27, no. 3, pp. 263 – 265, March 1992.

[17] J. Stein, R. Caissy, A. P. Plamondon, and P. Y. Bernier, "Estimation of Potential Evapotranspiration with Shallow Lysimeters in a Forest Tree Nursery", *The Forestry Chronicle*, vol. 71, no. 6, pp. 755 – 758, November 1995.

[18] R. M. Feltrin, J. B. D. Paiva, E. M. C. Paiva, and F. A. Beling, "Lysimeter Soil Water Balance Evaluation for an Experiment Developed in the Southern Brazilian Atlantic Forest Region", Hydrological Process, Wiley Online Library, vol. 10, 2011.

[19] J. H. Prueger, J. L. Hatfield, K. Aase, and J. L. Pikul, "Bowen-Ratio Comparisons with Lysimeter Evapotranspiration", *Agronomy Journal*, vol. 89, no. 5, pp. 730 – 736, 1997.

[20] R. Meissner and M. Seyfarth, "Measuring Water and Solute Balance with New Lysimeter Technique*", 3rd Australian New Zealand Soil Conference*, December 2004.

[21] D. Chan, P. Rajeev, C. Gallage, and J. Kodikara, "Regional Field Measurement of Soil Moisture Content with Neutron Probe", *In Proceedings of the Seventeenth Southeast Asian Geotechnical Conference*, May 2010.

[22] S. R. Evett and J. L. Steiner, "Precision of Neutron Scattering and Capacitance Type Soil Water Content Gauges from Field Calibration", *Soil Science Society of America Journal*, vol. 59, no. 4, pp. 961 – 968, August 1995.

[23] S. R. Evett, "Exploits and Endeavors in Soil Water Management and Conservation Using Nuclear Techniques", In proc. *International Symposium on Nuclear Techniques in Integrated Plant Nutrient, Water and Soil Management*, Vienna, Austria, 2001.

[24] C. Hignett, and S. R. Evett, "Neutron Thermalization", Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods, *Agronomy Monopgraph*, 3rd. ed., no. 9, 2002.

[25] S. R. Evett, L. J. Paul, C. Peter, and H. Clifford, "Neutron Scattering Capacitance, and TDR Soil Water Content Measurements Compared on Four Continents", *17th World Congress of Soil Science*, vol. 59, no. 1021, pp. 1 – 10, August 2002.

[26] D. S. Chanasyk and M. A. Naeth, "Field Measurement of Soil Moisture Using Neutron Probes", *Canadian Journal of Soil Science*, vol 76, pp. 317 – 323, 1996.

[27] M. E. Medhat, "Application of Gamma-Ray Transmission Method for Study the Properties of Cultivated Soil", *Annals of Nuclear Energy*, vol. 40, pp. 53 – 59, 2012.

[28] W. A. Dorigo, W. Wagner, R. Hohensinn, S. Hahn, C. Paulik, A. Xaver, A. Gruber, M. Drusch, S. Mecklenburg, P. V. Oevelen, A. Robock, and T. Jackson, "The International Soil Moisture Network: A Data Hosting Facility for Global In Situ Soil Moisture Measurements", *Hydrology and Earth System Science*, vol. 15, pp. 1675 – 1698, 2011.

[29] E. C. Martin, "Methods of Measuring for Irrigation Scheduling", Agricultural Agricultural & Biosystems Engineering, University of Arizona, Tucson, In 2nd Annual Four Corners Irrigation Workshop, pp. 51 – 59, 2001.

[30] S. R. Evett, "Some Aspects of Time Domain Reflectometry (TDR), Neutron Scattering, and Capacitance Method of Soil Water Content Measurement", International Atomic Energy Agency, Vienna, Austria, pp. 5 – 49, 2000.

[31] F. S. Zazueta and J. Xin, "Soil Moisture Sensors", Florida Cooperative Extension Service, Institute of Food and Agricultural Science, University of Florida, Buletin 292, pp. 1 – 11, April 1994.

[32] F. Plauborg, B. V. Iversen, and P. E. laerke, "In Situ Comparison of Three Dielectric Soil Moisture Sensors in Drip Irrigated Sandy Soils", *Vadose Zone Journal* by Soil Science Society of America, vol. 4, pp. 1037 – 1047, November 2005.

[33] I. Ismail, J. C. Gamio, S. F. A. Bukhari, and W. Q. Yang, "Tomography for Multi-Phase Flow Measurement in the Oil Industry", *Flow Measurement and Instrumentation*, vol. 16, pp. 145 – 155, 2005.

[34] W. Nijland, M. V. Maijde, E. A. Addink, and S. M. Jong, "Detection of Soil Moisture and Vegetation Water Abstraction in a Mediterranean Natural Area Using Electrical Resistivity Tomography", *Catena*, vol. 81, pp. 209 – 216, 2010.

[35] W. Q. Yang and L. Peng, "Image Reconstruction Algorithm for Electrical Capacitance Tomography", *Measurement and Science Technology*, vol. 14, no. 1, 2002.

[36] D. Chen, X. Deng, and W. Q. Yang, "Comparison of Three Electrical Capacitance Tomography Systems", *IEEE International Conference on Imaging Systems and Techniques (IST)*, pp. 57 – 62, August 2010.

[37] W. Q. Yang and T. A. York, "New AC-Based Capacitance Tomography System", *IEEE Proc. Measurement and Science Technology*, vol. 146, pp. 47 – 52, 1999.

[38] A. Chondronasios, W. Q. Yang,and V. T. Nguyen, “Impedance Analyzer Based Tomography System”, *Proc. of 2nd World Congress on Industrial Process Tomography*, pp.573-579, 2001.

[39] B. H. Brown, “Medical Impedance Tomography and Process Impedance Tomography: A Brief Review”, *Measurement Science & Technology*, vol. 12, no. 8, pp. 991 – 996, August 2001.

[40] T. York, “Status of Electrical Tomography in Industrial Applications”, *Journal of Electronic Imaging*, vol. 10, pp. 608 – 619, March 2001.

[41] X. Hu, M. Yang, Y. Li, W. Q. Yang, “An Impedance-Analyser-Based Multi-Channel Imaging System and Its Applications”, *Imaging Systems and Techniques, IEEE*, vol. 8, September 2008.

[42] W. Q. Yang, A. Chondronasios, S. Nattrass, V.T. Nguyen, M. Betting, I. Ismail, H. McCann, “Adaptive calibration of a capacitance tomography system for imaging water droplet distribution”, *Flow Measurement and Instrumentation*, vol. 15, pp. 249 – 258, July 2004.

[43] W. Q. Yang, “Key Issues in Designing Capacitance Tomography Sensors”, *5th IEEE Conference on Sensors*, pp. 497 – 505, October 2006.

[44] B. Almashary, S. M. Qasim, S. Alshebeli, W. A. Al-Masry, “Realization of Linear Back Projection Algorithm for Capacitance Tomography using FGPA”, *4th World Congress on Industrial Process Tomography Aizu Japan*, 2000.

[45] C. G. Xie, S. M. Huang, B. S. Hoyle, R. Thorn, C. Lenn, D. Snowden, M. S. Beck, “Electrical Capacitance Tomography for Flow Imaging: System Model for Development of Image Reconstruction Algorithms and Design of Primary Sensors”, IEE Proceedings-G, vol. 139, no. 1, pp. 89 – 98, February 1992.

APPENDICES

APPENDIX A

GANTT CHART

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Perform experiment on soil moisture measurement	■	■	■	■				Mid Semester Break								
2	Submission of Progress Report	■	■	■	■	■	■			●							
3	Project work continues							■		■	■						
5	Result and data analysis						■	■		■	■	■	■				
6	Pre-EDX												●				
7	Finalize results and findings											■	■	■			
8	Submission of Draft Report														●		
9	Submission of Final Report and Technical Paper															●	
10	Oral presentation																●

● Suggested Key milestones   ■ Process

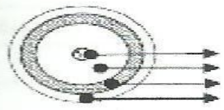
APPENDIX B

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-17F/119F

CONSTRUCTION



1. Conductor
2. Dielectric
3. Screen
4. Sheath

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-17F/119F

1) Conductor		
Elongation at break	≥ 1%	
3) Screen		
Coverage	86 %	
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
Electrical characteristics (cont..)		
Power rating at..	100 MHz	≤ 50 W
	1000 MHz	≤ 16.5 W
Nominal attenuation at..	400 MHz	80 dB/100m
	1000 MHz	148 dB/100m
Maximum attenuation	10% higher	

MARKING
Text — Inkjet printing

POPE VENLO HOLLAND RG 174 U MIL-C-17F

PACKAGING

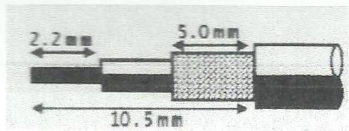
Code 46968 0025 040	One way reel E 250/100/160 Length 500 m ± 5% Max. 10 % of the length to be delivered contains a shorter length with a minimum of 250 m. Each reel or coil contains one length of cable
Code 46968 0025 153	Ring 200 m ± 5% Max. 10 % of the length to be delivered contains a shorter length with a minimum of 50 m.

Weight	
Total cable	11.50 g/m
Copper	4.82 g/m

APPENDIX C

STRAIGHT FEMALE CRIMP PLUG

Technical Data



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