CHAPTER I
INTRODUCTION

1.1 Background

Soil serves as the fundamental source of life for all human beings, of which the quality playing a crucial role in determining agricultural sustainability, environmental quality, as well as the health of plants, animals, and humans [1][2]. One approach to assess the quality of soil involves estimating its condition by utilizing a set of independent indicators that correspond to specific soil properties. These indicators encompass physical, chemical, and biological aspects of the soil [3]. These characteristics are employed to analyze the level of soil fertility, including factors such as the percentage of sand and silt in the soil, nutrient content, and water content. These measurements are of great significance to the agricultural sector as its provide valuable information about the soil suitability for cultivation and its ability to support plant growth [4][5].

Multiple studies [6][7][8] emphasize that the water content in the soil is a vital parameter that directly influences plant growth and requires careful observation. It serves as a reference point during the irrigation process, ensuring that an optimal balance of water is maintained, avoiding both excessive and inadequate moisture levels to obtain the quality of the vegetation. The quality of vegetation can be compromised when soil has an excess of water, as it leads to waterlogged roots. This condition hampers root respiration due to oxygen depletion, thereby reducing vegetation quality. On the other hand, insufficient water in the soil can cause permanent damage to vegetation due to drought. By monitoring and managing the soil water content (SWC), plant health and growth can be effectively supported [9].

Having a reliable technique is essential for determining the SWC, as it helps prevent harm to plants. Moreover, the estimation outcome serves as a valuable guideline for determining the ideal timing and amount of fertilizer application. Several research inform that the SWC measurement divided into two measurement method, the direct measurement method such as the gravimetric method [10] and indirect measurement method such as Ground Penetrating Radar (GPR)[11][12], Time Domain Reflectometry (TDR) [13][14], and Microwave Sensor [15][16]. The primary distinction between direct and indirect measurements lies in their approach: direct measurements utilize the mass of the soil to measure and estimate soil water content

(SWC) levels, while indirect measurements rely on the electrical characteristics of the soil during the SWC level assessment which utilize the electromagnetic wave to sensing [17].

The gravimetric method categorized as the direct measurement of the soil water content with technically straightforward approach [10][18]. The method involves obtaining a soil sample from a specified depth, transporting it to the laboratory, weighing and drying it, and then calculating the results based on the dried sample [19]. This method is widely utilized as calibration standard for another proposed method due to high level of accuracy [20]. However, a significant drawback of these methods is their time-consuming nature, which can result in longer periods required to obtain the measurement results [21]. Additionally, this methods does not allow for easy replication at the same location which fail to provide comprehensive SWC profile information for the entire area.

The commonly used method for measuring soil water content (SWC) levels is Ground Penetrating Radar (GPR). This method employs a signal generator to produce electromagnetic waves transmitted through the transmitter into the soil area being tested. GPR offers high accuracy of detection, but it involves complex algorithms to process the data and derive the SWC levels. Due to its suitability for larger-scale measurements, like tea plantations, it may not be the most appropriate choice for small-scale measurements [12][17].

In TDR method [22], multiple metal rods or electrodes are employed and buried within the material under examination. These electrodes play a crucial role in recording the electric pulse throughout the sensing process. Using TDR for data collection offers the advantage of easy adjustment for automation, enabling efficient monitoring of soil water content (SWC) levels. However, this method has its limitations as it may not be suitable for saline alkaline soils and can be influenced by soil voids, affecting the accuracy of the results. Moreover, at a smaller scale, TDR requires complex electronic equipment compared to the microwave sensor approach [23].

Microwave sensors are capable of measuring various properties of materials and provide provide valuable information about moisture content, density, structure, shape, and even chemical reactions of the materials being analyzed. Compared to traditional sensors, microwave sensors offer several advantages. These include rapid measurement, non-destructive, high precision, ability to reduce power consumption, and the ability to be created either in a laboratory setting or for on-site applications[24]. This method have a compact design and is well-suited for small-scale SWC measurements. However, to obtain the SWC level results, it is crucial to discover an appropriate mathematical formulation based on the microwave sensor design, enabling the translation of sensing data into accurate SWC result [25]. The fundamental principle of a microwave sensor involves transmit the electromagnetic wave through the transmitter towards to a soil sample to observe the electronic property of the soil, dielectric permittivity. Several studies[25][26] show due to achieve accurate results, a microwave sensor relies on a sensing transmitter, particularly an antenna, which plays a crucial role in the sensing process.

The antenna serve as the important part of microwave sensor which have direct interaction with the soil sample under test to obtain its dielectric permittivity value. This value is extracted by observing the resonant frequency, a parameter of the antenna, during sensing process [24]. In this application, the antenna need to have the high sensitivity characteristic to obtained the accurate result. One way to assess the sensitivity of the antenna is by observing the shift in the resonant frequency when different soil samples are sensed. The higher resonant frequency shifted, the higher the sensitivity of the antenna to changes in the dielectric properties of the soil samples. This measurement of sensitivity allows for the evaluation of the antenna capability to detect and differentiate even subtle variations in the electronic characteristics of the soil. Based on [24][27] the design and properties of the antenna are important to ensure accurate and precise measurements of the dielectric permittivity of the soil sample.

Recently, there has been a rapid advancement in antenna development, with numerous types and designs proposed for various applications. According to several studies, such as [25],[26], and [28], the microstrip antenna has been suggested as a sensor antenna. In the research conducted by [26], a microstrip antenna was proposed for glucose monitoring. The experiment result demonstrated good sensitivity of the microstrip antenna, as evidenced the shift of the resonant frequency was recognize when the sample was changed. After data processing,it was observed the shift of the resonant frequency of 3.53 KHZ represent the concentration of 1 mg/dl of glucose. Another study cite as [25] proposed the utilization of a microstrip antenna as a sensor for monitoring product quality. The objective of this research was to investigate the variation in resonant frequency when detecting the water content in milk. The findings indicated that changes in the concentration of water in milk caused a shift in the resonant frequency. Furthermore, the results demonstrated the potential of this technique for identifying the dielectric permittivity of various unknown materials.

Several studies have suggested focusing on the shape of the microstrip antenna patch to achieve a highly sensitive antenna, specifically a rectangular patch for the microstrip antenna. In a publication referenced as [29], a design for a rectangular patch antenna with enhanced sensitivity is proposed for measuring the permittivity of planar materials. The placement of a planar dielectric substrate above the patch resulted in a noticeable shift in the resonant frequency of the input reflection coefficient. The designed patch antenna exhibited an improved sensitivity, ranging from 3 to 5 times higher, when tested with various samples having different dielectric constants.The design of a rectangular microstrip patch antenna operating at 900 MHz is intended for moisture measurement. It has been noted that variations in the moisture content lead to changes in the resonant frequency and return loss values of the antenna [30].

As discussed earlier, estimating the SWC level relies on obtaining the dielectric permittivity through the extraction of resonant frequency results from the experimental process and applying a specific mathematical formulation. To ensure accuracy, it is essential to propose an appropriate mathematical equation based on resonant frequency which obtained. By analyzing the combined data gathered from simulations or experimental processes, the mathematical formulation for estimating soil water content can be derived. Depending on the suitability with the data collection, the result of the mathematical formulation can be in several form of a linear, exponential, or polynomial equation. Based on the [31], the data collection can be procced use Matlab simulatior to obtained the suitable form of the mathematical formulation.

As the previous literature [15] - [31], This study centers around the development of a small-scale method to measure and estimate soil water content (SWC) levels. It utilizes the high sensitivity of a rectangular microstrip antenna acting as a microwave sensor for SWC measurements. Furthermore, the study also focuses on the development of a dedicated mathematical formulation was conducted to determine the dielectric permittivity, leveraging the resonant frequency behavior of the proposed design during interaction with the soil sample. It is utilize the theoretical approach, numerical approach by using CST simulator and the difference between those two data. The mathematical formulation will be applied during the experimental process, and its results will serve as input to estimate the SWC level. To verify the precision of the proposed design and mathematical formulation, the gravimetric method was employed. A comparison was made between these two sets of measurements to assess the accuracy of the proposed design in estimating the SWC level.

1.2 Problem Formulation

Estimating SWC is benefial and fundamental, particularly in the agricultural sector especially for small area observation. The existing methods for obtaining SWC suffer from limitations such as a time consuming, complexity, and high costs. Hence, there is a need to explore alternative methods that offer real-time capability, reduced complexity, and compactness. In addition, it was necessary to observe and discover adjustable and easy method to obtained the mathematical formulation based on the measurement design. The accurate mathematical formulation are required which establish the relationship of the detection parameter and the SWC level in order to obtained the result precise SWC level.

1.3 Objective

The objective of this research is to identify an effective method for estimating SWC. This research proposed the microstrip antenna as microwave sensor and this study aims to develop a mathematical formulation which obtained from consideration theoretical approach data collection, numerical approach by using simulator data collection and difference from both of them, which can used as conversion formula between detection parameters into values of SWC. Futhermore, this project aims to evaluate method suitability to profiling the SWC level from entire area observation through the utilization of a microstrip antenna as a microwave sensor. Additionally, it serves as a validation process to determine the feasibility of employing microstrip antennas for sensing purposes that go beyond their traditional application in mobile communication.

1.4 Scope of Work

Based on the problem formulation, the scopes of the problem in this thesis are:

1. This research focuses on design and realization microstrip antenna as microwave sensor.
2. The microstrip antenna proposed would work at resonant frequency 955 MHz of which the design and simulation process would be done using software.
3. The antenna parameter observed is resonant frequency which obtained from return loss graph.

4. The experiment is designed to assess the sensitivity and accuracy of the proposed method, as well as to evaluate the one soil sample can representative the how larger area within the experimental area.

5. The soil samples are taken from the lowland and taken in depth of 5 - 10 cm from under ground level which is defined as organic horizon.

6. The thickness of the soil sample during measurement is 5 cm.

7. The method to obtain mathematical formulation are used the simulator which Matlab.

8. The data collection for the mathematical formulation involved three main approaches: the theoretical approach, the numerical approach using CST simulator, and incorporating additional input from the differences between these two approaches. The dedicated microstrip antenna used for data collection operated in frequency of 955 MHz.

9. The results of the mathematical formulation exhibit specific characteristics applicable only to the 800 - 1000 MHz frequency range of the microstrip antenna. However, the data collection method and the approach used to obtain the mathematical formulation can be adapted and utilized for other frequency ranges of the microstrip antenna.

10. The detected SWC value is written in percentage unit.

1.5 Methodology

The process steps in completing this thesis are detailed as follows:

1. Literature Study
   The purposes of this step are to collect study literatures from papers, journals, previous researches as well as books which are related to SWC, methods to estimate SWC, microwave sensor, antenna sensor, theoretical concept covered rectangular antenna, specifications of the antenna design to be used from the resonant frequency and the calculation method of antenna dimension, relation between dielectric permittivity and antenna parameter and to determine the literature to be used as references in this thesis. In addition, it is to support the processes of completing this thesis.

2. Design and Simulation
   The designing process of an antenna begins with establishing initial dimensions of the antenna, which will then be simulated using a software. By software simulation of the antenna, various parameters such as radiation pattern and return loss can be analyzed and assessed. The simulation results provide valuable insights into the antenna's performance characteristics and aid in determining the necessary optimizations required to improve its efficiency and functionality.

3. Numerical and mathematical approach
   Numerical and mathematical approaches are applied to investigate the relationship among microstrip antenna parameters, resonant frequency, and the electronic properties of soil, specifically the dielectric permittivity. The main objective is to establish an adjustable formulation that accurately estimates SWC values. By considering the theoretical concepts and conducting experiments, the study is aimed to validate the proposed method and mathematical equation to demonstrate the feasibility and effectiveness of the proposed approach within an experimental scope, validating its accuracy and reliability for estimating the SWC.

4. Measurement and Experiment
   A measurement is conducted to assess the quality and performance of the implemented antenna. This involved observing the value of S11 and ensuring the specified threshold to be met. The experiment is conducted following the validation of the antenna's satisfactory performance. It involves placing soil samples on top of the antenna sensor and performs the tests. The experiment employs two different methods: the proposed method using a rectangular microstrip antenna sensor, and the calibration method involving gravimetric measurements. The data collected from both experiments will be used to estimate the SWC.

5. Data Processing
   After collecting data from the previous steps, the resonant frequency processing is conducted using a mathematical equation to approximate the value of dielectric permittivity, which will be applied for estimating the SWC. Additionally, the data from the gravimetric method is processed, and the results are used for comparison with the proposed method.

6. Analysis
   The analysis is carried out in two stages. The first stage involves an analysis

based on simulation and mathematical approaches. The objective of this analysis is to assess the sensitivity of the proposed rectangular antenna by way of using the simulation results as a starting point and it is followed by incorporating theoretical considerations. This analysis serves as the base for the second stage, which focuses on experimental results. Furthermore, the analysis includes an examination of the observed changes in the resonant frequency during the experiment and continue to the analysis of the dielectric permittivity values which are processed using mathematical methods. Finally, the estimated SWC obtained from the proposed method is compared with the results obtained from the gravimetric method, serving as the calibration method
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7. Conclusion
   After obtaining the results of the analysis, conclusions were obtained.

1.6 Thesis Structure

The systematics for writing this thesis is as follows:

1. Chapter 1 INTRODUCTION This chapter contains the background, problems, objectives, research methods, and systematic writing.
2. Chapter 2 BASIC THEORY This chapter contains an explanation of the theories, concepts, tools related to research.
3. Chapter 3 RESEARCH METHODOLOGY This chapter contains the workflow and system design flow.
4. Chapter 4 RESULTS AND ANALYSIS This chapter contains the steps of test results, and an analysis of the test results obtained.
5. Chapter 5 CONCLUSION This chapter contains the conclusions and suggestions of this thesis.