CHAPTER 3 METHODOLOGY

3.1 Introduction

This methodology outlines the development of an automatic plant watering system that utilizes soil moisture sensing technology to monitor soil moisture levels and deliver water to plants as needed. By integrating sensor technology with automated watering mechanisms, this system aims to optimize plant health, minimize water usage, and reduce manual intervention in plant care management.

3.2 Methodology By Objective

3.2.1 Objective 1

Design and develop a prototype sensor capable of detecting soil moisture content with an accuracy of 95% across a range of 10% to 100% saturation.

3.2.1.1 Theories and Concepts

A. Dielectric Permittivity:

Soil moisture content significantly influences the dielectric permittivity (ε) of soil, which measures its ability to store electrical energy. Dry soil typically exhibits lower permittivity, while wet soil has higher permittivity due to the presence of water molecules. This fundamental principle underpins many soil moisture sensor designs. The dielectric permittivity of a material (ε) is calculated using the formula:

$$\boldsymbol{\varepsilon = k\,\varepsilon_0}$$

Equation 1. Dielectric permittivity of a material

where:

- ε, *the absolute permittivity of the material*
- *k, the relative permittivity or dielectric constant of the material*
- $\varepsilon_{0,}$ *the permittivity of free space or vacuum*

The relationship between soil moisture and dielectric permittivity forms the basis for indirect moisture content estimation in soil.

B. Capacitance:

Capacitance, representing the ability to store electrical charge, plays a vital role in soil moisture sensing. By measuring the capacitance (*C*) between two electrodes inserted into the soil, changes in dielectric permittivity due to varying moisture content can be indirectly assessed. The formula for capacitance between two parallel plates is:

$$C = \frac{\varepsilon A}{d}$$

Equation 1. Capacitance formula

where:

- *ε, the dielectric permittivity of the material between the plates*
- *A, the area of overlap between electrodes*
- *d, the separation distance between electrodes*

In soil moisture sensors, the dielectric permittivity of the soil alters the capacitance between the electrodes, providing a basis for estimating soil moisture levels. This relationship is fundamental to the operation of capacitance-based soil moisture sensors and informs the design and calibration processes to ensure accurate moisture measurements.

3.2.1.2 Hardware Components

A. Sensor Electrodes

Developing a soil moisture sensor starts with selecting the most efficient material for the sensor electrodes, prioritizing conductivity and corrosion resistance. Copper will be used as the sensor electrodes due to excellent conductivity, and durability, which is crucial for accurate capacitance measurements in soil moisture sensing applications. Electrode size and shape are then optimized for efficient capacitance measurement, with prototyping techniques like 3D printing or PCB fabrication enabling iterative testing of configurations to enhance sensitivity and accuracy. These sensor electrodes will be connected to the microcontroller unit for data collection and analysis.

B. Sensor Calibration

Sensor calibration is a critical hardware process that involves adjusting and fin-tuning a sensor’s output to accurately correspond with known or expected values of the measure parameter. To facilitate the calibration of soil moisture sensors, a ceramic capacitor will be used. The ceramic capacitor will be used to establish reference points for sensor calibration based on the capacitance variation with soil moisture content. By comparing the capacitance measurements of the ceramic capacitor, which represents a known reference value, with the output readings of the soil moisture sensor at different moisture levels, a calibration curve is generated. This calibration curve serves as a reference for adjusting the sensor output to accurately reflect soil moisture levels, ensuring the sensor provides precise and reliable measurements across a range of soil conditions.

C. Analog to digital converter

The analog to digital converter module will convert the analog capacitance signal from the sensor electrodes into a digital signal that the microcontroller unit can understand.

The analog-to-digital converter (ADC) plays a crucial role in the calibration process by facilitating the conversion of the analog capacitance signal obtained from the sensor electrodes into a digital format that the microcontroller unit can interpret and process. In the calibration procedure using a ceramic capacitor, the ADC precisely measures the capacitance of the ceramic capacitor, which serves as a known reference point for soil moisture levels. By accurately digitizing the capacitance value, the ADC enables the microcontroller to compare the sensor's output readings with the reference capacitance values obtained from the ceramic capacitor.

Moreover, the ADC's resolution and accuracy are essential factors in ensuring the precision of the calibration process. Higher-resolution ADCs allow for finer adjustments and more accurate representation of capacitance values, leading to improved calibration accuracy for the soil moisture sensor. Additionally, the ADC's sampling rate determines the frequency at which capacitance measurements are taken, influencing the sensor's responsiveness and ability to capture rapid changes in soil moisture levels.

Overall, the ADC serves as a vital interface between the analog capacitance signal from the sensor electrodes and the digital processing capabilities of the microcontroller, facilitating accurate calibration and ensuring the reliability of soil moisture measurements for agricultural and environmental applications.

D. Microcontroller Unit

For the system, a microcontroller unit (MCU) will be used. The MCU will be a low-power design to efficiently manage sensor operations and process readings. The MCU will be equipped with a minimum of 32KG of flash memory, 2KB of SRAM, and a clock speed of 16MHz to handle sensor data acquisition and potential signal conditioning tasks. Additionally, it will incorporate analog-to-digital conversion (ADC) capabilities to accurately convert analog sensor signals into digital data for further processing.

Figure N. Sensor module block diagram.

3.2.1.3 Software Components

An embedded software that controls the operation of the sensor module. The software will reside on the microcontroller unit (MCU). The software will be designed to perform the following tasks:

A. Control Signal Generation

Control signal generation is a critical component of the soil moisture sensor system, facilitating the initiation of capacitance measurement between the sensor electrodes and enabling the retrieval of relevant data. The software is responsible for generating precise control signals that trigger the sensors to commence the capacitance measurement process. These control signals will be sent in the form of commands or instructions from the microcontroller unit to the sensor module. The software ensures that these signals are issued at the appropriate times and with the necessary parameters to initiate accurate and reliable capacitance measurements. Timing considerations are crucial in control signal generation to synchronize the measurement process with other system operations and optimize the sensor's performance. The software also implements feedback mechanisms to monitor the status of the sensors and verify the successful execution of control signal commands. By continuously monitoring sensor responses and system health, the software can adaptively adjust control signal parameters or initiate corrective actions as needed, enhancing the stability and robustness of the soil moisture sensor system

Figure N. Control signal generation flowchart

B. Analog to Digital Conversion

Analog-to-digital conversion (ADC) serves as an essential step in the soil moisture sensing process, enabling the translation of analog capacitance measurements obtained from the sensors into a digital format that can be processed by the microcontroller unit (MCU). As the receiver of analog data from the sensors, the software plays a crucial role in collecting and managing the raw capacitance readings. It coordinates the data acquisition process, ensuring that measurements are captured accurately and efficiently. Once the analog data is received, the software passes it to the ADC module for conversion, orchestrating the interface between the sensors and the MCU.

The software governs the ADC's operation, configuring its parameters such as resolution, sampling rate, and reference voltage to optimize the accuracy and precision of the conversion process. By setting appropriate ADC settings, the software ensures that the analog capacitance signals are faithfully translated into digital values, preserving the integrity of the sensor data. Additionally, the software may implement calibration algorithms to compensate for ADC non-linearities or offset errors, further refining the accuracy of the digital output. Through effective coordination and control of the ADC, the software enables seamless integration of sensor data into the digital domain, laying the foundation for subsequent analysis, interpretation, and decision-making by the MCU.

Figure N. ADC flowchart

C. Calibration Routine

For enhanced accuracy, the software incorporates routines that utilize a reference capacitor. By comparing measurements from the soil and the reference capacitor, the software will compensate for any slight variations in the sensor hardware, leading to more consistent readings across different sensor units. ***<More details needed>***

Figure N. Calibration routine flowchart

D. Noise Filtering and Signal Processing

Recognizing that real-world electrical measurements can be plagued by noise, the software will incorporate filtering techniques such as moving averages to smooth out random fluctuations. Additionally, depending on the noise characteristics, Fast Fourier Transform analysis will be employed to remove specific noise frequencies or compensate for noise-induced errors. These strategies aim to refine the raw capacitance data, ensuring clean and stable readings for accurate soil moisture estimations. ***<More details needed>***

Figure N. Noise Filtering and signal processing

E. Conversion of Raw Data to Soil Moisture

The software module for converting raw data to soil moisture will utilize a pre-determined calibration curve, derived from empirical testing, to translate the raw capacitance readings acquired from the ADC into estimated soil moisture content. During the calibration phase, the sensor will be exposed to soil samples with known moisture content across a range of saturation levels (e.g., 10% - 100%). Statistical analysis techniques, such as regression analysis, will be employed to establish a mathematical relationship between the raw capacitance readings and the actual soil moisture content. This relationship will form the basis of the calibration curve, which maps the raw capacitance values to corresponding soil moisture levels. The conversion algorithm will then integrate this calibration curve, utilizing interpolation or curve fitting techniques to calculate the estimated soil moisture content based on the mapped values. By employing this approach, the software module will effectively convert raw capacitance data into meaningful soil moisture values, enabling the automatic plant watering system to precisely regulate water delivery based on the moisture needs of the plants.

Figure N. Conversion of capacitance to soil moisture.

3.2.1.4 Testing

A. Sensor Calibration

A set of one hundred (100) soil samples of varying moisture content from 10% to 100% will be prepared and used for the testing. The sensor will be calibrated using a controlled environment with the soil samples of known moisture content. The moisture content of the selected soil sample will be determined using a commercially-available, industry-grade soil moisture sensor. The sensor will be inserted into the same soil sample and record the measured capacitance. The relationship between measured capacitance and actual moisture content will be established to create a calibration curve for the sensor.

B. Accuracy Testing

A different set of one hundred (100) soil samples will be used for this testing. The sensor will be tested across the entire target range (10% - 100% moisture content) using various soil types to assess its accuracy. The testing will involve comparing sensor readings with gravimetric measurements (drying a soil sample to determine its moisture content by weight loss). The goal is to achieve a 95% accuracy rate across the entire range.

C. Repeatability Testing

The sensor will be subjected to multiple measurements under the same conditions to evaluate its repeatability and consistency in readings. The test will be repeated three (3) times using one hundred (100) soil samples of varying moisture content.

D. Environmental Testing

The sensor's performance will be evaluated under different environmental conditions, considering temperature variation and soil texture, to ensure its robustness and reliability in real-world applications. To conduct this test, the sensors will be used in actual garden, outside of laboratory area, where accuracy testing will be conducted.

3.2.2 Objective 2

3.2.2.1 Theories and Concepts

3.2.2.2 Hardware Components

3.2.2.3 Software Components

3.2.2.4 Testing

3.2.2 Objective 3

3.2.3.1 Theories and Concepts

3.2.3.2 Hardware Components

3.2.3.3 Software Components

3.2.3.4 Testing

3.3 Integration and Overall Testing

3.4 Conclusion