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ISSN (Online) 2394-6849

International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)

Vol 10, Issue 12, December 2023

Assessing the Reliable Data for Wireless Sensor Network-Based Capacitive Soil Moisture Sensor Monitoring System

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Abstract*— Providing accurate soil humidity information with a capacitive sensor is challenging. The humidity of the soil is known to change slowly. However, due to the nature of the capacitive sensor, which is sensitive to environmental disturbance, the received humidity reading taken by the sensor could change drastically which is not reflecting the actual soil humidity conditions. In reducing the variations, data averaging could be incorporated. It is known that the longer the averaging points the lesser data fluctuation will be. However, in wireless sensor applications where energy usage should be as minimum as possible, the faster the sampling period gives more energy penalty. In this paper, an empirical experiment to determine how fast the data sampling and the number of averaging points result in the best soil humidity data taken by a capacitive sensor is presented. With the criteria of least data variance with the smallest sampling period result in 200 ms data sampling with a 1000-point average gives the best data quality.

***Keywords*—soil humidity, wireless sensor, energy, data variance.**

I. INTRODUCTION

Since time immemorial, agriculture has been one of the main occupations in many countries. Despite this, the industry still needs a lot of growth. Precipitation and how it infiltrates have a large impact on yield. However, many farmers are concerned about reduced rainfall. Irrigation systems were developed in response to this problem to manage water effectively. Drip inundation is today's most effective way to ensure water reaches the roots of plants. We also need to make sure that our industries are using water efficiently. Soil moisture can be used to determine if a plant needs water at a particular time. Utilizing a dielectric moisture sensor is another method. Since the dielectric constant (the ratio of a material's permittivity to that of air) changes as moisture acts (as the permittivity changes), the capacitance of the sensor will also vary. These sensors are essentially capacitors, with the soil serving as the dielectric part [1]-[2].

A. Background

Capacitive Soil Moisture Sensors: An electronic component that, when energized, stores electrical energy in an electric field is known as a capacitor. It is made up of two metallic surfaces that are separated by an environment or dielectric material. Capacitance, which is the term used to describe the amount of energy that can be stored in a capacitor, is defined by Eq. 1 [3].

$$C = \epsilon k \frac{A}{d} \quad (1)$$

where C is the capacitance, ϵ is the environment's electrostatic permittivity, k is the environment's dielectric constant, A is the area of the metal surfaces, and d is the distance between them.

Because the material or environment surrounding or between the plates has a different capacitance [3], any change in the amount of water in the soil around the capacitor plate will change both the capacitance and the sensor oscillator step, which will change the output voltage. We are able to establish a connection between the measured sensor value and the water content [4]. Photovoltaic cells or the feed channel of a microcontroller can be used to power capacitive soil moisture sensors [5]. Given the dependability of their responses, researchers readily accept capacitive soil moisture sensors despite their relevant temperature sensitivity and limited detection range [6].

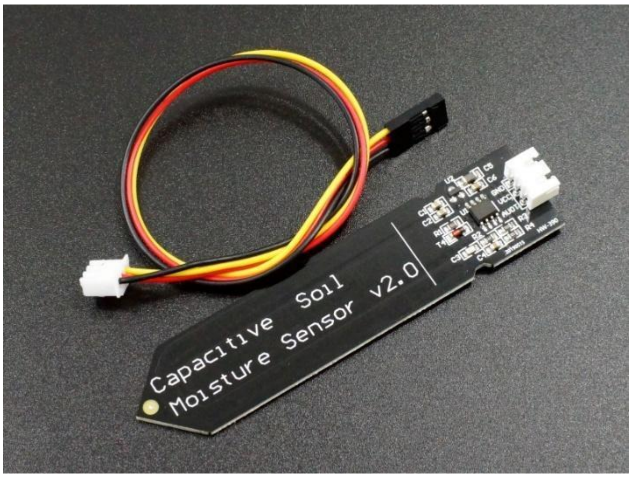

Fig. 1. Capacitive soil moisture sensor

ESP32 development board: ESP32 is a Wi-Fi development board that integrates Bluetooth Low Energy (BLE), which is widely used in IoT applications. This board is based on

ISSN (Online) 2394-6849
International Journal of Engineering Research in Electronics and Communication Engineering (IJERECE)
Vol 10, Issue 12, December 2023

Espressif Systems' ESP WROOM32 module. The compact module operates at 3.3V and consumes low power, making it suitable for battery-powered portable applications.

Fig. 2. ESP32 development board

TABLE I. Technical specifications of Esp32

Operating Ratings		
Vcc	Range	3.3 to 5.5V
I(typ)		< 5mA
Vout	Analog Output Range @ 5V	1.2V to 3V (typ)
Dimensions		
Sensor Probe	L x W (PCB)	98 x 23mm (3.86 x 0.91″)
Cable	Length	20cm (8″)

A capacitive-type electromagnetic soil moisture sensor is calibrated using a gravimetric approach in this technique. Capacitive soil moisture sensors take advantage of the dielectric difference between water and soil, which has a value of about 80 for water and 2-6 for dry soils, respectively [7]. For agricultural applications where the under and over-watering of the soil may result in ineffective or wasted resources, accurate monitoring of the soil's water content is essential [8]. Since depending on the specific porosity of the soil, water might fill up to 60% of certain soils by volume, calibration is required in every location to assure accurate water content production [9]. As sensor prices have dropped, measurement accuracy has increased. In this project, a microcontroller is programmed using the Arduino platform to read the analog data from a capacitive sensor, which successively emits a voltage. This voltage's inverse is frequently a linearly acceptable approximation of the volumetric soil moisture content. This is accomplished by weighing and measuring the soil at various moisture levels. Data taken from the sensor gives some variations. This variation is very fast if compared to the speed of change of the soil humidity.

B. Motivation

The health of plants, which in turn influences the health of our food, is a crucial concern for soil moisture in smart agriculture.

The evapotranspiration mechanism controls soil moisture, meaning that plants draw water from the soil to make their own sustenance. Each plant uses a different quantity of water depending on its size and the type of soil it is growing in.

Plants won't be able to generate enough food if the soil is too dry; as a result, they will require more water than usual and may wilt or even die if you do not give them adequate care. That same plant can struggle to thrive or possibly drown if your soil is overly damp.

One can keep track of how much water your plants require and when they are receiving it by checking the soil moisture.

C. Objective

For agricultural applications, measuring soil moisture is crucial because it enables farmers to run irrigation systems more efficiently. When farmers are aware of the precise soil moisture conditions on their fields, they are not only able to produce crops with less water overall, but they can also better regulate soil moisture during crucial plant growth phases to increase yields and crop quality.

Soil moisture sensors are used in urban and suburban settings to link with irrigation controllers for residential lawns and landscaping. A simple irrigation clock may be upgraded to a "smart" irrigation controller by adding a soil moisture sensor. This controller will stop watering cycles when the soil is already moist, as is the case after a recent downpour event.

To check whether plants have enough moisture to live, there are easy, reasonably priced gadgets that do not need a power source. A meter evaluates if the soil is too dry, humid, or moist for plants after placing a probe into it for around 60 seconds.

II. METHODOLOGY

The amount of water in the soil is determined via a sensor known as a "soil moisture sensor." It contains two leads that must be placed into the soil in order to measure the amount of water in the soil. Based on the supplied settings, the ESP32 microcontroller programs the necessary action for automatic watering using the input of the soil moisture content.

The experiment's goal is to gather data over a variety of periods and with various averaging points. Gathering six distinct sets of data over a variety of periods at various averaging points.

- Data 1: 500 as the average, 100 ms as the sampling interval.
- Data 2: 500 as the average, 10 ms as the sampling interval.
- Data 3: 100 as the average, 10 ms as the sampling interval.

- Data 4: Averaging point is 1000, and the sampling time is 10 milliseconds.
- Data 5: 1000 as the average point, 100 ms as the sampling interval.
- Data 6: 500 as the average, 200 ms as the sampling interval.

Generate six graphs and determine the sample variance following the collection of all data. Farmers and users alike can benefit from data with a low sample variance.

In the example, the soil was dried, but this is unnecessary because the ground needs to be hydrated to expand to a usable capacity. So, it was advised to select a sort of dirt that was already slightly dried up but was still loose enough to pack in the sensor. The experimentation procedure might become somewhat simpler as a result. The analog signal from the capacitive sensor is read using Arduino code. The capacitive sensor's signal is accessed by the Arduino code using analog pin A0. The Arduino reads the signal as bits, thus it is frequently transformed to a voltage by multiplying by the 3.3V input reference and dividing by the 10-bit resolution. Once the code has been uploaded to the Arduino board, the capacitive sensor ought to read a voltage of about 3.15V. This could be a test to see if the sensor is working properly.

The amount of information needed and whether to choose manual or automated instruments will determine how long it takes to monitor soil moisture. As the selected irrigation trigger point approaches, collect data more often (daily) between watering events. Ensure that the appropriate amount of water was applied during or after an irrigation event.

The capacitive soil moisture sensor may be calibrated simply by following these steps:

1. Connect the capacitive soil moisture sensor to the Arduino to prepare the hardware.
2. Prepare a plant in a soil-filled container.
3. Put the capacitive sensor on the ground.
4. Make a note of the readings. This measurement shows the lowest capacitance level.
5. Now, gradually pour water into the beaker until the soil is nearly soaked. Hold on a second.
6. Read the capacitance number again. This reading represents the highest value.
7. Map the moisture level read from the actual application between 0% and 100% using these values.

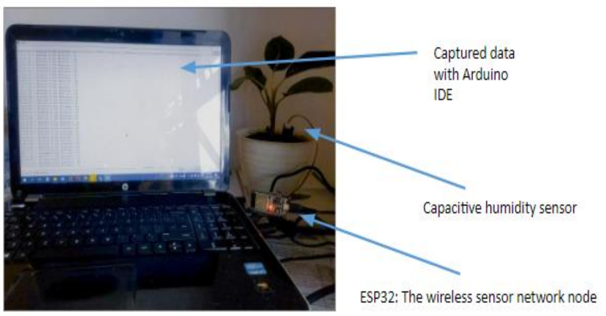

Fig 3. Soil Moisture Monitoring

Initial conditions about the experiments:

- There were six experiments have been done inside an air-conditioned room with the temperature kept at about 24 to 27 degrees Celsius with various sampling and averaging parameters.
- The Arduino IDE was used to collect soil moisture data.
- Each experiment was done in about 1 hour.
- All data collects with the capacitive soil moisture sensor.
- Table II explains the sampling period and averaging points for each of the experiments.

TABLE II. Data parameters

Name	Sampling Period	Averaging Points	Figure
Data 1	100 ms	500	Fig. 5
Data 2	10 ms	500	Fig. 6
Data 3	10 ms	100	Fig. 7
Data 4	10 ms	1000	Fig. 8
Data 5	100 ms	1000	Fig. 9
Data 6	200 ms	1000	Fig. 10

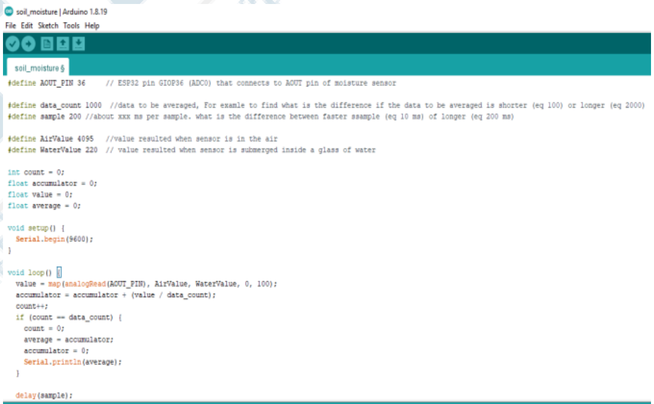

Fig 4. Arduino IDE programming for soil moisture measurement

Figure 4 describes the Arduino IDE programming for soil moisture measurement, where data to be averaged, For example, to find what is the difference if the data to be averaged is shorter (eq 100) or longer (eq 2000) and about xxx ms per sample. what is the difference between a faster sample (eq 10 ms) and of longer one (eq 200 ms).

III. RESULT

Figures 5,6,7,8,9 and 10 display the moisture content vs. time for various average points across different time intervals. The moisture level is between 100 and 104 according to all the graphs. Yet, we can observe that out of all the charts, figure 8 is the smoothest.

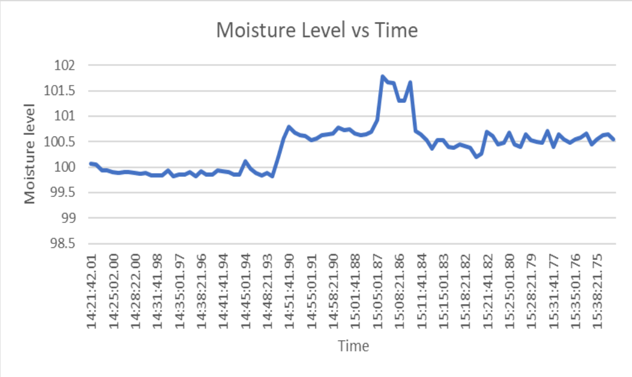

Fig 5. The moisture level for Data 1 (averaging point 500 with 100 ms time period)

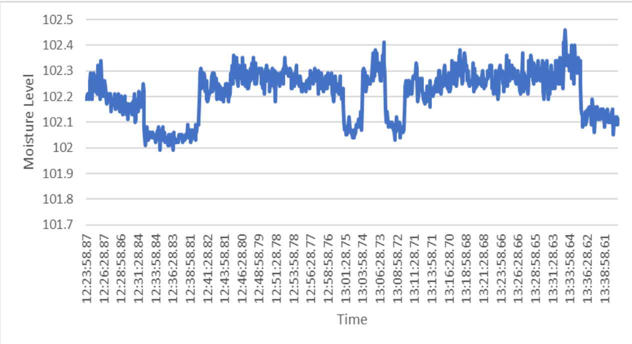

Fig 6. The moisture level for Data 2 (averaging point 500 with 10 ms time period)

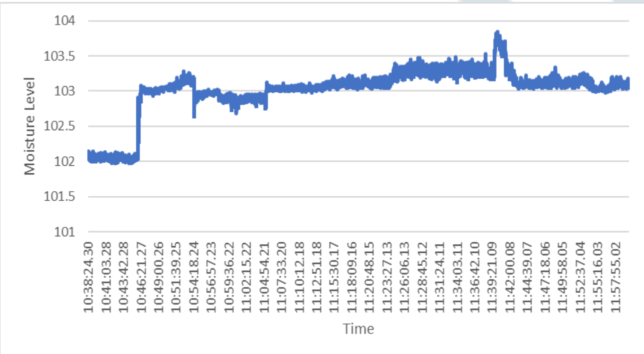

Fig 7. The moisture level for Data 3 (averaging point 100 with 10 ms time period)

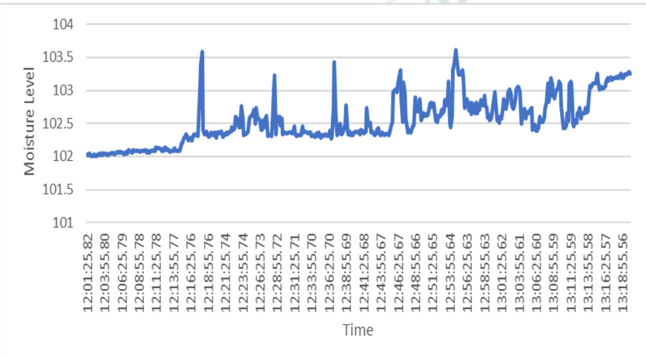

Fig 8. The moisture level for Data 4 (averaging point 1000 with 10 ms time period)

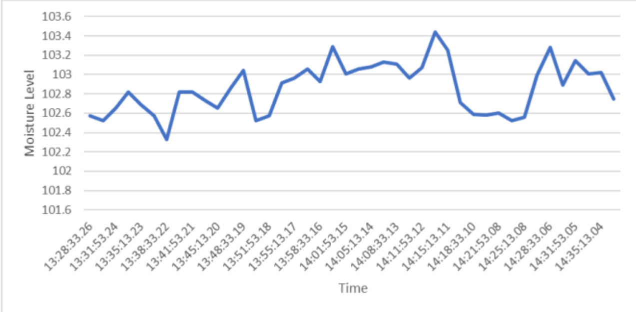

Fig 9. The moisture level for Data 5 (averaging point 1000 with 100 ms time period)

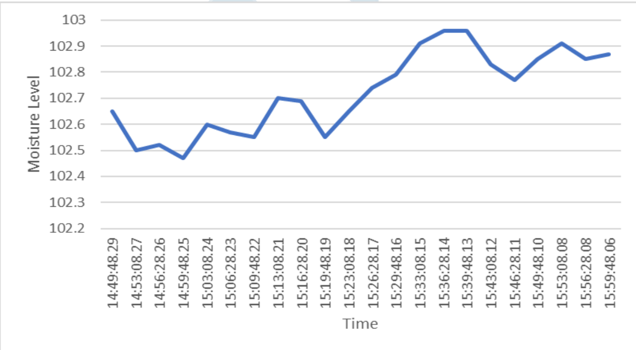

Fig 10. The moisture level for Data 6 (averaging point 1000 with 200ms time period)

IV. DISCUSSIONS

Some descriptive statistical analyses have been done on the data and presented in Table III. It can be seen from the table that the data range is quite small, less than 2% within 1 hour. The smallest range was found in Data 2, which is 0.47. This indication can also be seen from the smallest sample variance of 0.009.

TABLE III. Statistical analyses on the humidity data

	Mean	Sample Variance	Range	Min	Max	Count
Data 1	100.3	0.261	1.96	99.82	101.78	72
Data 2	102.2	0.009	0.47	101.99	102.46	720
Data 3	103.0	0.140	1.55	101.98	103.53	3600
Data 4	102.4	0.101	1.61	102.00	103.61	360
Data 5	102.8	0.066	0.92	102.33	103.25	19
Data 6	102.7	0.024	0.49	102.47	102.96	18

Increasing the averaging points indicates a smaller data variance. Data 4 averages 10 times more data compared to Data 3 and results in a smaller sample variance as indicated in Table IV. This result is consistent as shown in Table V which shows that averaging 2 times more data in Data 5 gives tighter sample variance compared to Data 1 with a similar sampling period. This indication is achieved with the exclusion of Data 2 in Table IV as this data shows an extraordinarily tight sample variance.

TABLE IV. Data with similar sampling period of 10 ms

	Avg point	Mean	Sample Variance	Range	Min	Max	Count
Data 2	500	102.2	0.009	0.47	101.99	102.46	720
Data 3	100	103.0	0.140	1.55	101.98	103.53	3600
Data 4	1000	102.4	0.101	1.61	102.00	103.61	360

TABLE V. Data with similar sampling period of 100 ms

	avg point	Mean	Sample Variance	Range	Min	Max	Count
Data 1	500	100.3	0.261	1.96	99.82	101.78	72
Data 5	1000	102.8	0.066	0.92	102.33	103.25	19

TABLE VI. Data with similar 1000 averaging points

	sample period	Mean	Sample Variance	Range	Min	Max	Count
Data 4	10	102.4	0.101	1.61	102.00	103.61	360
Data 5	100	102.8	0.066	0.92	102.33	103.25	19
Data 6	200	102.7	0.024	0.49	102.47	102.96	18

Achieving the conclusion that the longest averaging points, 1000 points in this case, gives the least sample variance can be used to help determine how fast the data sample should be taken. With the help of Table VI, it can be seen that the longest sample period, 200 ms, gives the tightest sample variance of 0.024. With this configuration, the soil humidity data is available every 200 ms. With this configuration, most of the time, ESP32 can be kept under sleep period therefore least energy is consumed while data accuracy can be achieved.

V. CONCLUSION

The intent of this research was to conduct a comparative analysis of data from various averaging points with various time scales with the least sample variance that indicates the best user-friendly data. The appropriate sample period was determined to be 200 ms with a 1000-point average after examining all the elements of the data and comparing and contrasting them. A time of 3.33 minutes is equal to 200 milliseconds multiplied by 1000. That implies that a valid data point is generated every 3.33 minutes. This is still quite good considering that soil humidity fluctuates in only a few hours or even minutes. Thus, the soil humidity monitoring scheme for the capacitive sensor and Wireless sensor node may use this sampling interval and average value. Getting high-quality data enables producers to care for their plants and offers insight into over- and under-watering.

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