Soil moisture prototype soil moisture sensor YL-69 for Gaharu (*Aquilaria malaccensis*) tree planting media

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ABSTRACT

Soil moisture, defined as the amount of water present in the spaces between soil particles, plays a critical role in plant growth. Excessive soil moisture can lead to issues such as root rot, deviating from the ideal conditions required for root absorption. To address this, we developed a prototype tool using the YL-69 soil moisture sensor to monitor and control the soil moisture levels in Agarwood/Gaharu tree planting media. The prototype was designed to activate a water pump when soil moisture exceeded 80%, ensuring optimal humidity for plant growth. Once the moisture level dropped below 80%, the pump was deactivated to prevent overwatering. The YL-69 sensor demonstrated an accuracy of 88.76% under controlled conditions. This study highlights the potential of using low-cost sensors for automated soil moisture management in small-scale Gaharu cultivation.

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1. INTRODUCTION

Agarwood (Gaharu) from *Aquilaria malaccensis* is a valuable non-timber forest product (NTFP) due to its high market price, driven by quality and essential oil grades [1], and demand, especially in the Middle East [2]. In 2001, in Pujangan, East Kalimantan, Gaharu reached Rp. 600,000/kg, with export values rising from US $2 million (1990-1998) to US $39.9 million in 2020 [3]–[5]. Found across Asia [6], this threatened species thrives in well-drained, sandy loam soils (pH 6.15, 80% humidity, 22-28 °C), not flooded areas [7], [8]. Overexploitation has made it rare, necessitating cultivation with suitable media [9], [10]. Soil moisture, critical for nutrient transport and growth, is addressed by this prototype, which measures moisture in Gaharu planting media using the YL-69 sensor and Arduino to aid farmers.

2. TECHNIQUES FOR MEASURING SOIL MOISTURE

In addition, keeping soil moisture at an ideal level for plants is essential. Soil moisture content can be measured using several different methods [11]–[13]. It is important to ensure that the soil remains moist, as this supports optimal plant growth and development [14]. Also, regular monitoring of soil moisture can help prevent problems such as a drought or waterlogging that can affect plant health. The most significant aspects of soil moisture affect the balance of key natural ecosystems such as seed germination, water infiltration, plant transpiration, redistribution, evaporation, and percolation are all aspects of plant nutrition and development. A plethora of experimental approaches for measuring soil moisture have been developed in recent decades [15].

2.1. Electrical methods

The standard for electrical estimation of soil moisture was first introduced in 1897 [16]. The framework measures the adjustment of the water mass from a metal barrel in the shape of a mousing circle example, using an accuracy balance, while the soil moisture measurement approach employs the electrical resistivity technique. Resistivity is needed in the estimated clock for this plastic cover. Using fluctuations in moisture content, the electrical resistance test calculates the soil's resistivity. The resistivity decreased from 338 ΩM to 8 ΩM while the volumetric moisture content increased from 5.8% to 38.5%. For dry soils, values greater than 50 Ωm cause the resistivity to react [17].

Time domain reflectometry (TDR) method is a method that utilizes the dielectric properties of dirt to estimate soil humidity levels. Dielectric stability estimate by estimating the electromagnetic wave's full circle velocity time at a consistent repeat (high repeatability from 30 MHz to 3 GHz) to and from the ground-covered metal terminal. The link analyzer provides high repeating electromagnetic pulses and filters out reflected waves, ground embedded poles, and links connecting analyzer and rods [18]. TDR estimates a small volume of soil, so no data of horizontal spatialization notice [19]. TDR sensors assess soil moisture by delivering electromagnetic pulses into the soil and evaluating how long the pulses take to travel through the soil. TDR offers precise depth measurements and is frequently utilized in environmental research and monitoring [20], [21].

The capacitance technique, this method estimates water content by estimating the dielectric consistency, which can estimate by capacitance. The dielectric steady of water is around 81 for wet soil, around 3 to 5 for dry soil, and 1 for air. The capacitance technique utilizes to gauge soil dampness content because of the consistent dielectric increments with expanding air content. Capacitance, C is straightforwardly relative to the dielectric steady. Gc addresses the structure factor, which relies upon the size and state of the sensor capacitance, and the distance between the electrode's ar content estimates by estimating the dielectric consistency, which estimates by capacitance. The dielectric steady of water is around 81 for wet soil, around 3 to 5 for dry soil, and 1 for air.

$$C = G_c K_d \tag{1}$$

The capacitance strategy utilizes to gauge soil dampness content K_d, because of the consistent dielectric increments with expanding air content. Capacitance, C is straightforwardly relative to the dielectric steady Where G_c addresses the structure factor which relies upon the size and state of the sensor capacitance and the distance between the anodes, the equation can see on (1) [22].

Figure 1 shows a capacitance technique for measuring soil moisture. Two electrode rods that enter into the ground make up the capacitance sensor. The ground serves as a dielectric and the two electrodes together make up a capacitor. On reading equipment, changes in electrical capacity are read and show changes in soil moisture [22]. By keeping the volume of each sample constant and concurrently measuring the mass of each sample, we reliably estimate soil moisture. This is achieved by using one of the containers with graduated markings and ensuring that the soil level remains constant while introducing water to the soil [23].

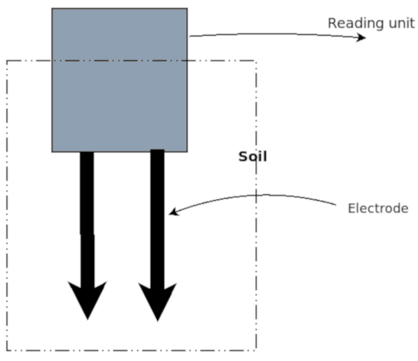

Figure 1. Schematic for the capacitance method of measuring soil moisture [22]

2.2. Non electrical methods

Wetness, the most frequent approach for measuring soil moisture is to collect a physical sample from the measurement location. The samples were weighed, then dried in an oven at 100 °C to 110 °C for 24 to 48 hours before being reweighed. In (2) calculates the gravimetric moisture content, often known as wettability (w).

$$w = \frac{Soil\ Mass_{wet} - Soil\ Mass_{dry}}{Soil\ Mass_{dry}} \quad (2)$$

The advantage of this system is that the sample is easy to obtain, and the moisture content is easy to determine. The destructive nature of the method offsets the possibility of repeating sampling at the exact location in the field. Second, w(Mg Mg-1), although a good indication of moisture status, is not as valuable for plant scientists as volumetric and potency humidity [24]. The amount of water that is accessible to plants (for transpiration) or the energy status of water cannot always be determined by measuring the water content of soil (or other porous media). Water will flow from high-energy to low-energy regions, with water potential indicating the energy condition [24].

The volumetric moisture content, other non electrical method is volumetric moisture content [24]. Groundwater status can determine by volume ($m^3\ m^{-3}$), where is the volume of the liquid phase per unit volume of bulk soil. This method is a popular method for providing soil moisture status information. However, measurements at the site must be repeated, especially during irrigation scheduling. If Θ is the degree of wetness, and the density of the soil is known, it can calculate by (3).

$$\Theta = w \times \frac{\rho_b}{\rho_w} \quad (3)$$

Where Θ is the degree of wetness, w is wetness ($Mg\ Mg^{-1}$), ρ_b is the bulk density of the soil ($Mg\ m^{-3}$), and ρ_w is the bulk density of water ($Mg\ m^{-3}$).
The bulk density of the soil can be calculated with a formula on (4).

$$\rho_b = \frac{dry\ soil\ weight}{Volume\ of\ sampler} \quad (4)$$

In this prototype, we combine two methods, the electrical capacitance technique and the wetness non-electrical technique. To get data from electrical devices which use the YL-69 sensor, we collect data by connecting it to Arduino.

3. RESEARCH METHOD

We conducted this study on 3 Agarwood (Gaharu) tree planting media (can see on subsection 4.2) with identical treatments. Sensors were placed on each medium, and the sensor measurements' results were recorded for each medium. We carried out this process by studying the characteristics of Agarwood trees, creating prototypes, and comparing the sensor measurement results with manual calculations.

3.1. Research model

The soil moisture control system for Agarwood trees uses a YL-69 sensor, 16x2 LCD, Arduino Mega 2560, motor driver, and DC pump. The sensor measures soil moisture, and the Arduino processes the data (Khalaf, 2021), displaying results on the LCD to control the pump.

3.2. Prototype design

3.2.1. Hardware design

This stage includes design using fritzing software, software design (source code compilation), and component design. Each step in the design stage will be interconnected so that the researcher can return to the previous step if there is a failure. The design uses a fritzing application to support the primary data collection of components and the placement of the pin wires that need in the development of the prototype. The design results are a reference in the form of components used in conducting development. More details can be seen in Figure 2.

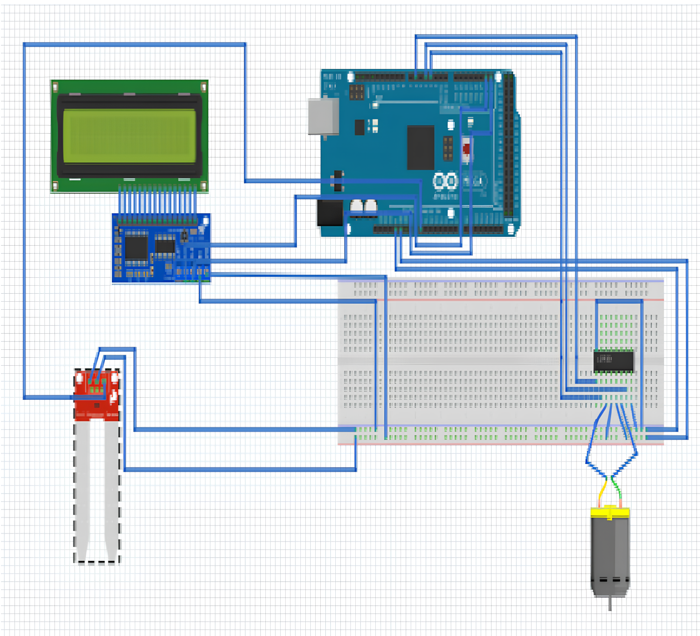

Figure 2. Design using fritzing

3.2.2. Software design

The proposed design for the soil moisture control system for Gaharu tree planting media utilizes various hardware components, including a soil moisture sensor (YL-69), a 16x2 LCD screen, an Arduino Mega 2560 micro-controller, driver motors, and DC water pumps. The system operates by measuring the moisture level of the soil using the YL-69 sensor and sending the data to the micro-controller, which then processes the information according to predefined procedures. The results of this processing are displayed on the LCD screen, which serves as a reference for activating the DC water pump to control the moisture level of the soil. The overall design of the system is illustrated in a diagram flow block design as shown in Figure 3. A basic outline of the process can be viewed in the algorithm referenced as Algorithm 1.

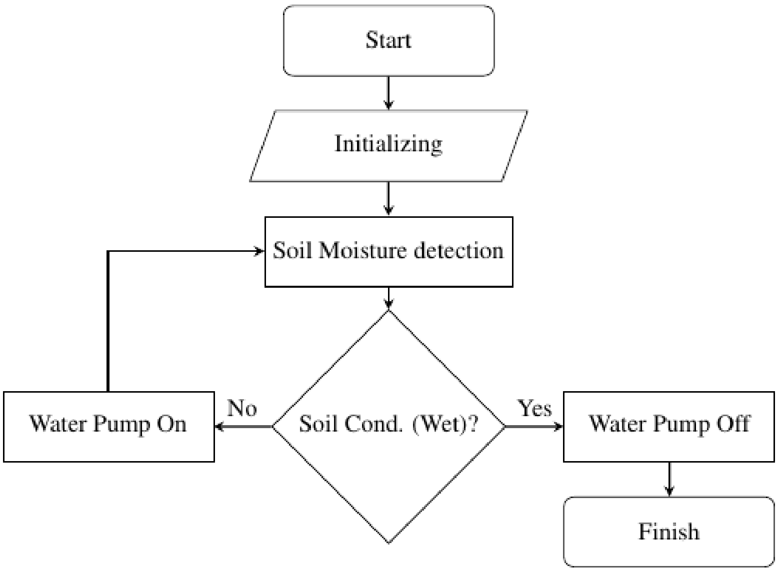

Figure 3. Process flowchart

Algorithm 1. Soil moisture control system

```
Initialize and calibrate the YL-69 sensor and the Arduino Mega 2560 microcontroller.
while true do
    Continuously measure the moisture level of the soil using the YL-69 sensor.
    Send the soil moisture data to the micro-controller for processing.
    if soil moisture level < threshold then
        Activate the DC water pump to add water to the soil.
    end if
    Display the current soil moisture level on the 16x2 LCD screen.
end while
Repeat steps 2-6 continuously to maintain proper soil moisture levels for the Gaharu trees.
```

3.2.3. Sensor calibration

The YL-69 sensor was calibrated using gravimetric water content, following a standardized procedure. Soil samples were dried at 105 °C for 24 hours to establish a baseline. The sensor readings were recorded and compared with manual calculations at 10% intervals of added water, from 0% to 100% soil saturation. The calibration process using gravimetric water content;

i) Prepare two containers filled with soil from the exact location (taken at the same time and depth) with a net weight of 100 gr each (container A and container B).
ii) The soil in container A dried using an oven at a temperature of 100-110 °C for 24 hours until constant weight.
iii) Calculate wettability (w) using grafitimatric methods, using (2).

$$w = \frac{Soil\ Mass_{wet} - Soil\ Mass_{dry}}{Soil\ Mass_{dry}}$$

iv) Calculate analog sensor voltage with a formula on (5) [25].

$$V_{sensor} = \frac{analog\ read}{1023} \times 5V \tag{5}$$

4. RESULT AND DISCUSSION

4.1. Non electrical and electrical gap

Our study suggests that after calibration of the sensor, we calculate the difference between the sensor readings used by manual calculations (nonelectrical). The weight of the soil used is 100 gr per sample and in dry condition (oven-dried for 24 hours and until the weight is stable). Then add water by spraying it slowly with a certain amount of water. The calculation results can see in Table 1.

Table 1. Soil moisture calculation results

No.	Soil dry weight (gr)	Water weight (gr)	Soil moisture (%)				Gap per exp.
			Manual	With a sensor			
				Med. A	Med. B	Med. C	
1	100	0	0	0.96	0.99	0.93	0.96
2	100	10	10	10.95	10.5	11.00	0.82
3	100	20	20	29.97	29.00	29.81	9.59
4	100	30	30	48.40	48.49	48.01	18.30
5	100	40	40	54.90	54.79	53.10	14.23
6	100	50	50	71.00	55.00	72.50	16.17
7	100	60	60	77.70	75.00	75.06	15.92
8	100	70	70	77.98	77.8	77.52	7.77
9	100	80	80	82.54	82.06	83.00	2.53
10	100	90	90	85.35	85.50	86.02	4.38
11	100	100	100	85.45	85.5	86.02	14.34
						Avg. gap	9.55

In Figure 4, it can see that there is a reasonably high fluctuation in sensor measurements. The low gap is at 10%, 20%, 80%, and 90% humidity measurements. Although the measurement fluctuations are pretty high, with an average gap of 9.55%, the prototype can be done because the desired soil moisture requirement is at the level of 80%.

Key findings: the YL-69 sensor demonstrated reliable accuracy at humidity levels up to 80%, making it suitable for small-scale agricultural applications. Beyond this threshold, the sensor's accuracy significantly decreased, with fluctuations reaching a maximum gap of 18.3% at 70% humidity. This limitation highlights the importance of sensor calibration and careful application in scenarios requiring precise soil moisture monitoring.

Interpreting results: the findings align with previous research on low-cost soil moisture sensors, which also report diminished accuracy at higher humidity levels due to the sensor's limited dielectric sensitivity. For instance, [26] found that sensors similar to YL-69 had reduced reliability in detecting soil moisture above 75% humidity. However, unlike previous studies that primarily focused on large-scale agricultural applications, our research emphasizes the practical viability of the YL-69 sensor for controlled environments and small-scale agriculture, particularly in Gaharu cultivation.

Figure 4 illustrates the sensor's performance across different humidity levels, highlighting significant gaps between 30% and 70% humidity. This indicates that while the YL-69 sensor is effective for small-scale applications, it shows limitations in maintaining accuracy for higher humidity ranges, which may impact its reliability for large-scale agricultural use. The prototype was done well, and the sensor has been able to detect soil moisture in the Gaharu planting media, where water pumps can water the soil at the desired humidity level. There are several disadvantages of the YL-69 sensor, as shown in Figure 4, where the sensor has a high gap at 30% to 70% humidity and then seems to continue to record values that do not change too much at 80 humidity.

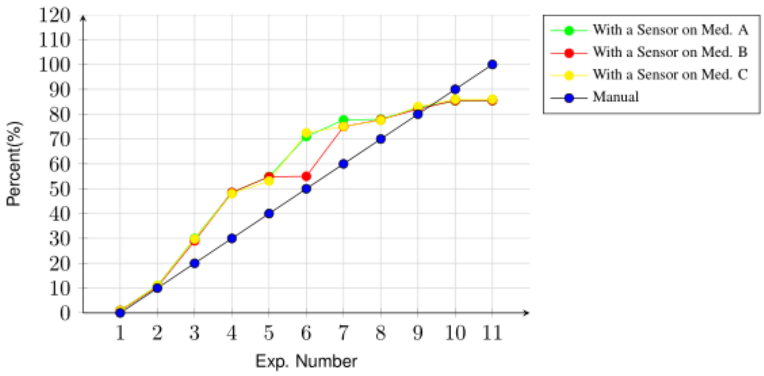

Figure 4. Calculation graph

4.2. Prototype

The prototype is designed as shown in Figure 5. There are three samples of Gaharu tree planting media with three water pumps. The three planting media used the same soil with the same humidity conditions.

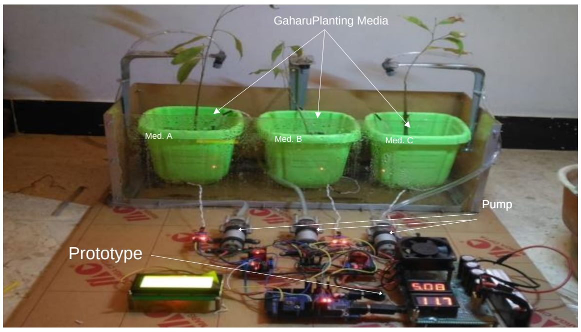

Figure 5. Prototype

The soil moisture regulator on Gaharu tree planting material is powered by a soil moisture sensor YL-69 and a specially programmed Arduino Mega 2560. The soil moisture sensor will detect the moisture level in the Gaharu tree soil medium. If the soil is dry, the Arduino Mega will command the water pump (a programmable water faucet) to turn on and irrigate the plants [27]. If the soil is wet, as the plant needs, the water pump will die, and the water will not flow. At 0% soil moisture, the water pump will irrigate the soil until it reaches the specified value, as shown in Table 2. In Table 2, it can see that the soil moisture sensor on Media A, B, and C reads 10% soil moisture data, so the water pump is on, and the water pump will still turn on if the soil moisture sensor reads the humidity data soil to 80%, then the water pump will stop.

Table 2. Water pump response to humidity

	Water presentation (%)								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Med. A	√	√	√	√	√	√	√	×	×
Med. B	√	√	√	√	√	√	√	×	×
Med. C	√	√	√	√	√	√	√	×	×

√ Water pump running on media
× Water pump stop on media

5. CONCLUSION

The prototype successfully demonstrated the capability of the YL-69 sensor in detecting soil moisture for Gaharu planting media. However, the sensor showed limitations in maintaining accuracy at certain humidity levels, indicating a need for improvement for larger-scale applications. The YL-69 sensor can be used for small scales, but larger scales, the sensor cannot measure humidity steadily. A more sensitive sensor can be used on a larger scale on agricultural land and potted planting media or polybags.

From the data presented, we can see how changes in the weight of added water affect the results of soil moisture calculations both manually and using sensors. Additionally, we can also see how accurate the sensor is in measuring soil moisture compared to manual calculations, as well as how the accuracy of the sensor varies depending on the amount of water added to the soil. It can be said that the YL-69 sensor has limitations in measuring humidity levels above 80%, so this prototype can be redeveloped using a different sensor or a more sensitive sensor can be used on a larger scale on agricultural land and potted planting media or polybags.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Rikie Kartadie	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Muhammad Agung Nugroho		✓	✓	✓	✓	✓		✓	✓	✓			✓	
Adiyuda Prayitna		✓		✓		✓		✓	✓		✓	✓		
Adi Kusjani	✓		✓			✓			✓		✓		✓	
Ardeaana Galih Mardika					✓		✓			✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal Analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject Administration
Fu : **Fu**nding Acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no financial, personal, or professional interests that could influence the results of this study.

DATA AVAILABILITY

The authors declare that no new data were generated or analyzed in this study. All information used is from published literature and is referenced in the article.

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