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Automatic Water Flow-Based Soil Moisture Monitoring System Oil Palm Nurseries

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ABSTRACT

There are many challenges and obstacles that often arise when caring for agricultural crops until harvest time arrives. One of the challenges in caring for oil palm seedlings is controlling soil moisture and maintaining the right water content for the seedlings. Many seedlings die because they do not get enough water, and sometimes extreme weather conditions make it impossible to water the plants. Farmers typically do not have the time to regularly monitor soil moisture and irrigation, especially for large areas. Based on this issue, there is a solution in the form of a soil moisture monitoring system with automatic irrigation based on the Internet of Things (IoT) to assist and simplify the management of these challenges. This study aims to design a soil moisture monitoring system with automatic irrigation to help farmers maintain soil moisture in seedbeds. This study uses the Research and Development (R&D) method to develop the previous system as a solution to the problem and improve the previous device. The result of this study is a prototype of an automatic irrigation-based soil moisture monitoring system with a DHT11 sensor and a soil moisture sensor. This system was tested based on calibration results showing that the sensor works with a regression equation. The coefficient of determination obtained for the DHT11 sensor was 0.95 and 0.89, for the soil moisture sensor was 0.91, and for the ultrasonic sensor was 1.0. Based on the regression equation obtained, the system can respond well to changes in temperature, humidity, and water levels to monitor soil moisture in seedbeds.

Keywords: Automatic Irrigation, internet of things, nursery, regression coefficient, soil monitoring system

INTRODUCTION

Indonesia is one of the largest producers of palm oil among countries in the world. (Nugroho *et al.* 2021). Palm oil as the primary raw material in the production of cooking oil, which is an essential commodity in daily life. According to a report from the Central Statistics Agency (BPS) in 2023, based on the area of land used, the total area is Oil palm plantations continued to increase from 2019 to 2023, but growth has nearly stagnated. By 2023, the total area of oil palm plantations is projected to reach 15.93 million hectares.

In order to obtain high-quality palm oil, palm trees are cared for from the moment they are planted. (Putro and Rasyid 2024). The palm oil seedling cultivation process requires monitoring of the condition of the seedlings, soil, and water content. Currently, there are many challenges and obstacles that hinder the cultivation process until the planting stage. (Saputra *et al.* 2023). One of the challenges faced is soil moisture composition and water irrigation. Data from the

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central statistics agency (BPS) shows that more than 55% of farmers in Indonesia still rely on unmeasured manual irrigation systems, which often results in water wastage and uneven irrigation. Controlling soil moisture levels and proper irrigation systems It is essential to maintain the seedlings until the planting season (Ningsih *et al.* 2021). Dependence on traditional irrigation methods is one of the obstacles to maximizing optimal palm oil seedlings (Effendi *et al.* 2024). Manual irrigation systems that are not adapted to environmental conditions often result in a mismatch between plant water requirements and the amount of water supplied. This problem is exacerbated by climate change, which causes unpredictable rainfall patterns (Utomo *et al.* 2021).

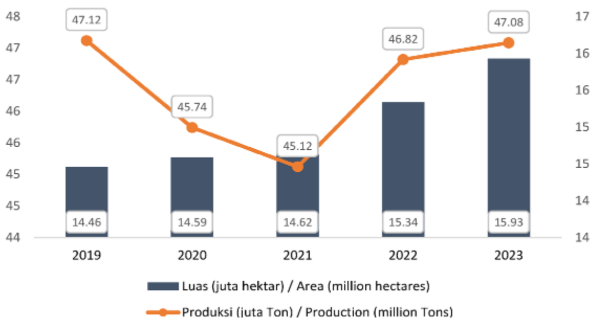

Figure 1 Area and Production of Indonesian Palm Oil, 2019–2023

The lack of an adequate system to monitor soil moisture and water availability makes it difficult for farmers to adjust the needs of oil palm seedlings to environmental conditions (Mahdi and Kasoni 2019). Palm oil farmers also do not have enough time and resources to monitor the condition of the seedlings. By utilizing current technological development solutions can be found to overcome these problems. Technological developments in the field of electronics can be utilized to overcome problems related to soil moisture monitoring and irrigation. Sensor techno-logy can be used to monitor environmental conditions for consideration in irrigating seedling nurseries (Suprasetyo *et al.* 2023). When environmental conditions and soil moisture levels allow for irrigation, then he automatic irrigation system will turn on irrigation gate (Novrizal 2019). This tool is equipped with IoT technology that can be monitored remotely via a smartphone. It is hoped that the use of this technology can help increase agricultural production, improve community welfare, and protect the environment.

MATERIALS AND METHODS

His study uses the Research and Development (R&D) method in assessing and designing research products. The tools produced are developments from previous studies, as well as experimental models to test the effectiveness of the tools when implemented (Sihombing *et al.* 2022). This activity will be carried out over a period of two months. The design of the tools and systems will be conducted offline at the Physics Laboratory, Padang State University, Jalan Prof. Dr. Hamka, Air Tawar Padang, West Sumatra. The electronic components that make up the soil moisture and automatic irrigation monitoring system are ESP32 as a microcontroller, DHT11 sensor, Soil Moisture sensor, Ultrasonic sensor, servo motor, water pump, relay module, jumper cable, and USB cable. Data collection techniques were carried out through observation and testing of the sensors and the system as a whole.

Data analysis was performed by conducting verification tests, meaning that after the optimal design was determined, the predicted response of the optimal design was also known. Then, verification experiments were conducted to compare the results with the predicted response. If the predicted response and the verification experiments were close to each other, it could be concluded that the design was adequate (Darusman and Sulaiman 2023). Conversely, if the verification experiment results are far from the predicted results, then the design is said to be inadequate. This device was designed as a prototype that illustrates the physical form of the system. Ultrasonic sensors are positioned at the top of the irrigation system, then the design is said to be inadequate. This device was designed as a prototype that illustrates the physical form of the system. Ultrasonic sensors are positioned at the top of the irrigation system, DHT11 sensors are installed around the field area, and Soil Moisture sensors are inserted into the soil.

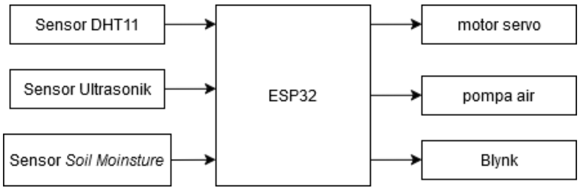

Figure 2 Working principle of tool components

Figure 3 is a mechanical design prototype of a soil moisture monitoring and control system for agricultural land. The tool works based on the soil moisture content in the targeted area. Soil moisture content is measured using the FC-28 Soil Moisture Sensor (Putra *et al.* 2024). All measured data will be sent to the ESP32. If the soil moisture is within a certain limit (moisture < 50%), the irrigation gate will open. When it reaches or exceeds a certain limit, the irrigation gate will close automatically. When the irrigation gate is open, the water in the irrigation system will automatically decrease and the water level will also decrease. An ultrasonic sensor will be used to measure the water level in the irrigation system. The ultrasonic sensor is placed 5 cm above the water surface. As the water level decreases, the distance between the sensor and the water surface automatically increases. If the distance between the ultrasonic sensor and the water surface exceeds 5 cm, the water pump will automatically turn on to refill the irrigation system.

The irrigation gate is operated using a servo motor as an actuator. When soil moisture is insufficient, the ESP32 will send a signal to the servo motor to open the irrigation gate. When moisture levels are adequate, the ESP32 will send a signal to the servo motor to close the irrigation gate again. Data from the ESP32 will be transmitted to the Blynk application.

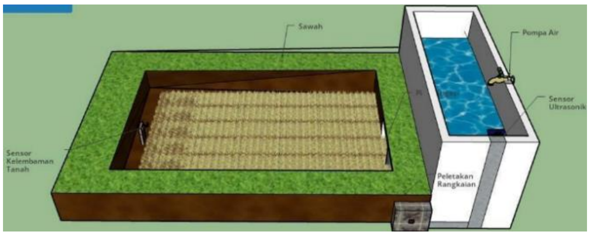

Figure 3 Design prototype system design

RESULTS AND DISCUSSION

The result of designing a prototype system for monitoring and controlling soil moisture and automatic irrigation based on IoT connected to the Blynk application. The size of the prototype system illustrates the design of the system on actual land. The hardware is designed with acrylic on irrigation, equipped with ultrasonic sensors and DHT11, while the Soil Moisture sensor is inserted into the soil.

Figure 4 Testing of equipment

System Software

The system software describes the mechanism for sending data from the ESP32 processing results to a cloud platform or server via a Wi-Fi network connected to the internet using the Wi-Fi module integrated into the ESP32. The data sent to the cloud is then stored and can be accessed by users through an interface via the Blynk application. In the Blynk application, the system measurement results can be displayed on a smartphone or computer screen to view the output from the device. The functionality of the DHT11 sensor in measuring temperature index in Figure 5 was tested under several conditions, namely placing the sensor at room temperature and placing the sensor outdoors. The sensor was also calibrated by comparing the measurement results with a standard device, namely a digital anemometer. The results obtained were then plotted in the following graph to find the sensor calibration equation. The Figure 6 shows a comparison of air temperature measurements with various treatments between the sensor and standard tools. The graph shows a linear regression relationship for both the sensor and standard tool measurements. The coefficient obtained for the DHT11 sensor is 0.97 with a calibration equation of $y = 0.035x + 25.85$ and a standard tool coefficient of 0.90. Based on testing, the calibration results are close to a coefficient of 1, meaning the sensor can detect environmental temperature precisely and accurately.

The Figure 6 shows a comparison of air humidity measurements with various treatments between the sensor and the standard device. The graph shows a second-order polynomial regression relationship for both sensor and standard device measurements. The coefficient obtained for the DHT11 sensor is 0.96 with the calibration equation $y = 0.0009x^2 - 0.0101x + 65.054$, and the coefficient for the standard instrument is 0.95. Based on the calibration test results, the coefficients are close to 1, indicating that the sensor can detect environmental temperature accurately and precisely.

Table 1 Test data for the DHT11 sensor in measuring temperature

No	Time (s)	Device Temperature (C)	Temperature on the standard device (c)	Percentage error (%)
1	10	26,3	26,6	1,12
2	20	26,4	26,4	0
3	30	26,8	26,6	0,75
4	40	27,2	26,9	1,11
5	50	27,8	27,5	1,09
6	60	28,1	28,01	0,32
7	70	28,3	28,1	0,71
8	80	28,5	28,2	1,06

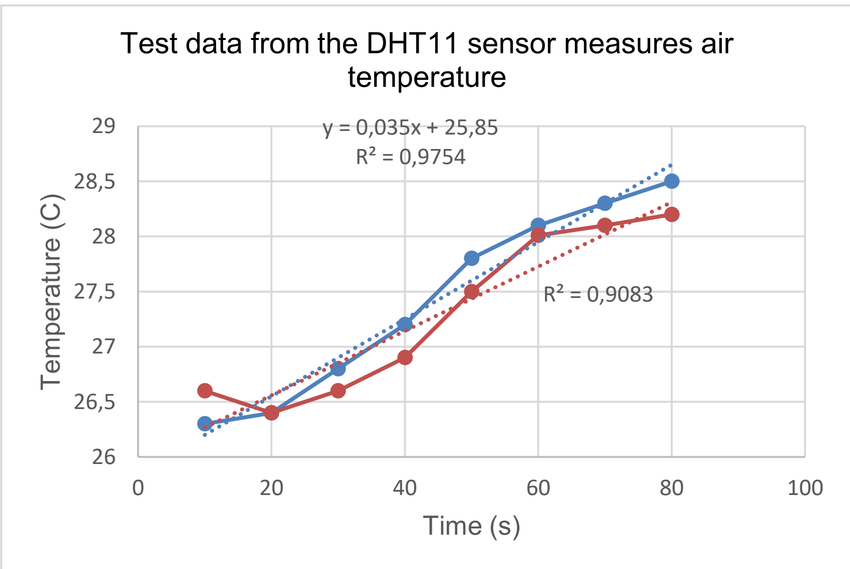

Figure 5 Testing graph of the DHT11 sensor in measuring temperature

Table 2 Testing the DHT11 sensor in measuring environmental humidity

No	Time (s)	Humadity of Device (%)	Standard instrument humidity (%)	Percentage error (%)
1	10	65	63,3	2,68
2	20	65	63,5	2,36
3	30	66	63,5	3,93
4	40	66	64	3,12
5	50	67	64,1	4,52
6	60	67	65	3,07
7	70	69	68	1,47
8	80	70	69	1,44

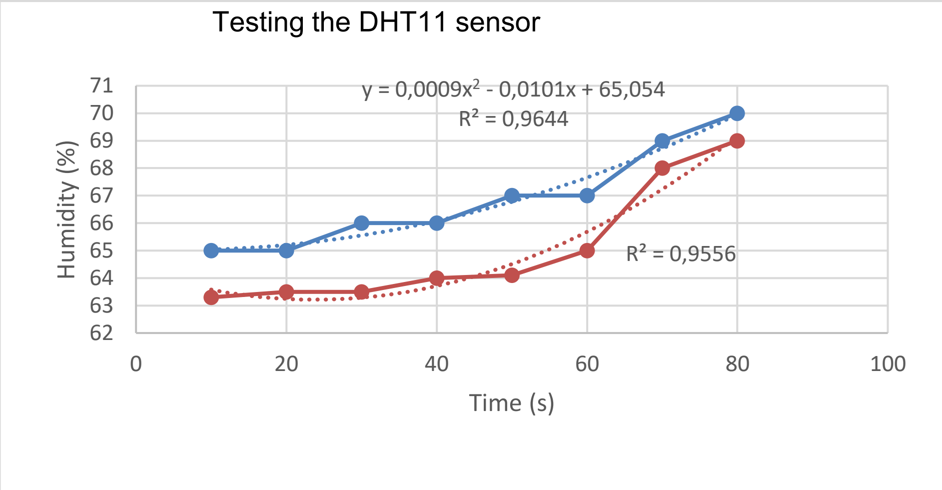

Figure 6 Graph of DHT11 sensor testing in measuring humidity

Soil Moisture Sensor Testing

Based on the calibration results of the Soil Moisture sensor with analog values in table 3, the uncertainty value is very small (in the range of 0.1–1.3%), indicating good accuracy of the sensor. The influence of soil conditions (moist, room temperature, or dry) does not seem to have a significant impact on the relationship between analog values and moisture in the given data. The relationship between analog values and soil moisture percentage is linearly decreasing, meaning that as soil moisture increases, the analog values of the sensor decrease.

Ultrasonic Sensor Testing

Based on the data in table 4, the ultrasonic sensor measurement values range from 2.2 cm to 12.91 cm. This data reflects the distance measured by the sensor. The ruler values show the actual distance reference values ranging from 2 cm to 12 cm. The calibration values are slightly different from the original sensor results, reflecting the sensor accuracy improvement process. The uncertainty indicates the error level of the sensor measurements compared to the actual values. The uncertainty values vary between 3.1% and 9.1%, with the average tending to be smaller at greater distances. The ultrasonic sensor has a fairly good level of accuracy.

The graph in Figure 7 shows the linear regression relationship of the sensor measurements. The coefficient obtained for the sensor is 1 with a calibration equation of y = 0.9247x + 0.3397. Based on the test results, the calibration coefficient is close to 1, meaning that the sensor can detect the ambient temperature precisely and accurately. The results of the system performance test measurements in table 4 showed temperature values ranging from 26.2°C to 33.2°C. The temperature tended to increase as the data changed. The humidity values ranged from 0.1 to 58%. Humidity tends to increase with higher temperatures. From the measurements, it was found that if humidity is below 40% and temperature is above 27°C, the servo motor will activate, and when humidity exceeds 40%, the servo motor will deactivate. If humidity exceeds 40%, the pump will shut off.

Table 3 Soil moisture sensor testing data

No	Sensor measurement	Calibration	Uncertainty (%)	Soil conditions
1	0	4089,1	0,1	Very humid
2	9	3716,9	0,1	Moist
3	17	3386,1	0,2	Moist
4	23	3138,0	0,1	Room Temperature
5	32	2765,8	0,2	Room Temperature
6	44	2269,5	1,3	Room Temperature
7	53	1897,3	0,5	Dry
8	64	1442,4	1,7	Dry

Table 4 Ultrasonic sensor measurement data

No	Sensor (cm)	Ruler (cm)	Calibration	Uncertainty
1	2,2	2	2,374	9,1
2	2,85	3	2,975	5,3
3	4,13	4	4,159	3,1
4	5,76	6	5,666	4,2
5	7,37	7	7,155	5,0
6	8,03	8	7,765	0,4
7	8,66	9	8,348	3,9
8	11,83	11	11,279	7,0

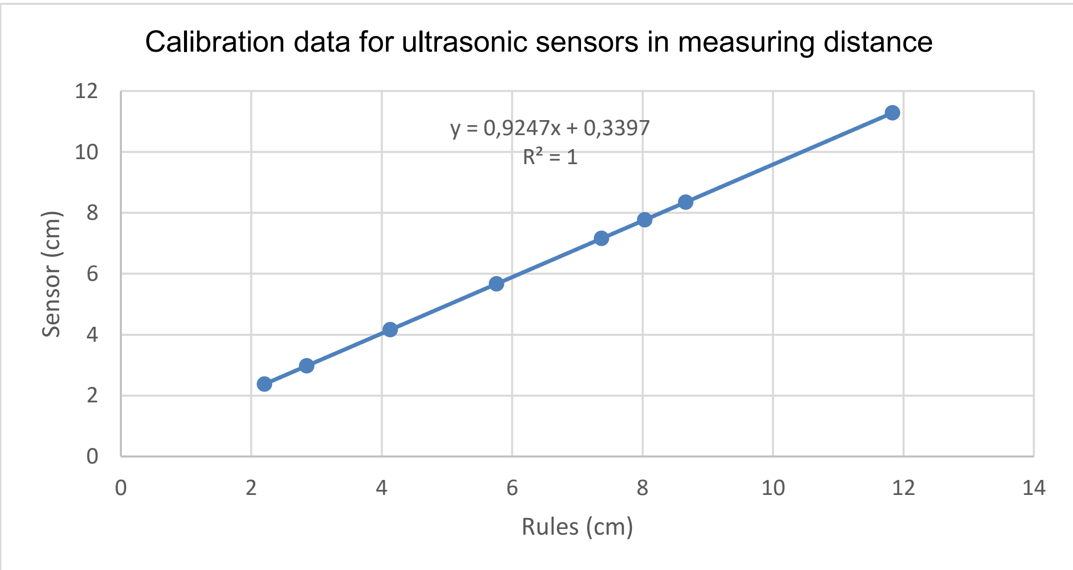

Figure 7 Graph of ultrasonic sensor testing in measuring distance

Table 5 Testing of the device system

No	Temperature (°C)	Humidity	Water distance	Servoak Motor Status	Pump Status
1	26.20	0.1%	5 cm	off	pump off
2	30	35 %	8 cm	on	pump on
3	31	43%	7 cm	off	pump off
4	31	45%	7 cm	off	Pump off
5	29.2	20%	8 cm	on	pump on
6	30.7	52%	4 cm	off	pump off
7	33	36%	5 cm	on	pump on
8	33.1	56%	6 cm	off	Pumpoff

CONCLUSION

This IoT-based automatic irrigation system measures soil humidity periodically and automatically regulates water flow, improving efficiency compared to conventional methods. The system was tested based on the calibration coefficients of each sensor: DHT11 for temperature and humidity at 0.97 and 0.96, Soil Moisture for soil moisture at 0.91, and Ultrasonic for water level at 1.0 and 0.96.

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