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# Testing of Soil Moisture and Temperature Sensors in an Automatic Plant Watering System Based on the Internet of Things (IoT)

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**Abstract:** The implementation of automated plant watering systems in the agricultural sector utilizes sensor technology based on the Internet of Things (IoT). This study aims to evaluate the performance of soil moisture and temperature sensors utilizing the IoT in an automated plant watering system. The sensors used are the YL-69 sensor to determine soil moisture and the DS18B20 temperature sensor to determine soil temperature. Both sensors are connected to the NodeMCU ESP8266 microcontroller. Testing was conducted from 07:00 to 17:00 WITA, with a 1-hour interval for data collection, monitored using the IoT on the blink application on the cellphone. Then, the data obtained is analyzed to determine the values of error and accuracy. The results obtained on the soil moisture sensor have an average error of 0.989% with an average accuracy of 99.011%. Meanwhile, the results obtained on the soil temperature sensor have an average error of 1.240% with an average accuracy level of 98.760%. The lower the error value, the better the sensor performance indicates the sensor's ability to read data that is close to the actual value of the comparison tool. Likewise, the higher the level of sensor accuracy, the better and more reliable the sensor is when used in an IoT-based soil temperature measurement system. This value indicates that the sensor's performance has a very high level of reliability and precision in detecting soil moisture and temperature in real-time. This system can be applied in agricultural technology education and vocational training programs.

**Keywords:** Internet of Things; Moisture; Plant Watering; Sensor; Temperature.

## Introduction

Recent advances in digital technology have driven the implementation of automation systems in agriculture. This system enables more precise irrigation schedules and volumes to be adjusted according to crop needs, thereby minimizing the risk of drought or excess water. Furthermore, automation also supports increased efficiency while reducing reliance on manual labor, given that irrigation systems are still performed manually in some areas of Gorontalo. One emerging innovation is an automatic plant watering system that utilizes soil moisture sensors and Internet of Things (IoT) technology, designed to optimize water use and minimize manual intervention [1]. Soil moisture sensors directly measure moisture levels in the field. With these sensors, the irrigation system can be automatically activated using IoT based on the actual needs of the land [2]. IoT-based automation systems offer real-time monitoring, data-driven decision-making, and remote device control, increasing water efficiency and enabling rapid, accurate responses to changing environmental conditions in tropical regions [3][4].

Although this technology offers modern solutions, at the local level, the agricultural sector is still the backbone of the Gorontalo community's economy. However, based on research findings, various challenges still face farmers in increasing productivity and efficiency; therefore, IoT-based innovations and intelligent algorithms are highly relevant to implement [5]. Most farmers in this region still rely on manual watering methods without considering the appropriate water requirements for each type of plant. This watering pattern not only causes inefficient water use but also has a negative impact on land productivity. Therefore, implementing an automatic watering system that integrates soil moisture and temperature sensors based on IoT technology is necessary [6]. Soil moisture directly reflects water availability to plant roots. Meanwhile, soil temperature affects microbial activity, nutrient absorption, and plant physiological processes [7]. The combination of the two provides a more accurate basis for IoT systems to make timely and proportionate watering decisions. This combination is expected to increase the effectiveness and efficiency of agricultural management, especially in tropical areas such as Gorontalo, which has humid and dynamic climate conditions.

Several previous studies have developed IoT-based automatic watering systems, but they still have several weaknesses. Developed an automatic watering system that utilizes a soil moisture sensor to control the pump; however, their system did not account for other environmental conditions, such as temperature and light intensity [8]. A soil moisture sensor to determine watering duration, but based on only one parameter, making it less adaptable to environmental changes [9]. Meanwhile, the study enabled online watering monitoring and control, but it was still limited to manual control and not fully automated. In general, previous systems were unable to adapt to environmental conditions such as air temperature, humidity, light intensity, and rainfall, which affect plant water needs [10].

Based on the presentations of previous researchers, this study will design an IoT-based automatic irrigation

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system that simultaneously monitors several environmental parameters, namely temperature and soil moisture. This system is capable of making more adaptive and accurate irrigation decisions based on real-world conditions. Thus, this research not only addresses the limitations of previous systems but also presents a more relevant solution for agricultural communities.

## Research Methods

This research began by developing an IoT-based automatic plant watering system that utilizes several sensors, including the YL-69 sensor to measure soil moisture and the DS18B20 temperature sensor to measure soil temperature. These two sensors are connected to the NodeMCU ESP8266 microcontroller, which serves as the central controller. Additionally, a water pump, relay module, breadboard, jumper cables, adapter, laptop, and Blynk application are utilised for IoT-based remote monitoring and control. Next, the program is uploaded to the NodeMCU and connected to the Blynk application, allowing sensor data to be monitored in real-time and the pump to be controlled automatically. The research flow diagram is shown in Figure 1. To ensure the accuracy of the system created, a comparison was made between the reading results of the sensors from the module and those obtained using conventional measuring instruments, as specified in the Indonesian National Standard (Standar Nasional Indonesia = SNI), namely a soil meter that manually measures soil moisture and temperature levels. Testing was conducted from 07:00 to 17:00 WITA, with data collection intervals of 1 hour, monitored by an IoT-based observer using the Blink application on a cellphone. Additionally, the automatic plant watering system monitoring will operate actively (ON)/inactively (OFF) based on the soil moisture standard for plants, specifically 40%-80% [11]. After that, the humidity and temperature data obtained are used to determine the error and accuracy of the sensor testing.

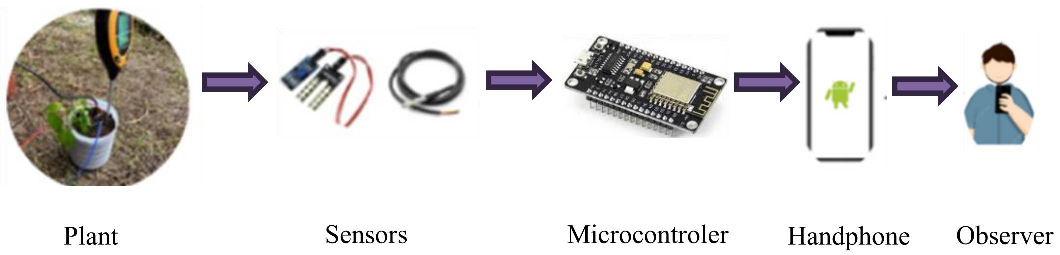


**Figure 1.** Research flow diagram for testing an IoT-based automatic plant watering system

## Results and Discussion

Testing of soil moisture and temperature sensors in an IoT-based automatic watering system using a NodeMCU ESP8266 microcontroller. Testing was conducted by comparing the sensor readings from the module with a conventional measuring instrument, a soil meter, which measures soil moisture and temperature. The test results are shown in Figure 2.

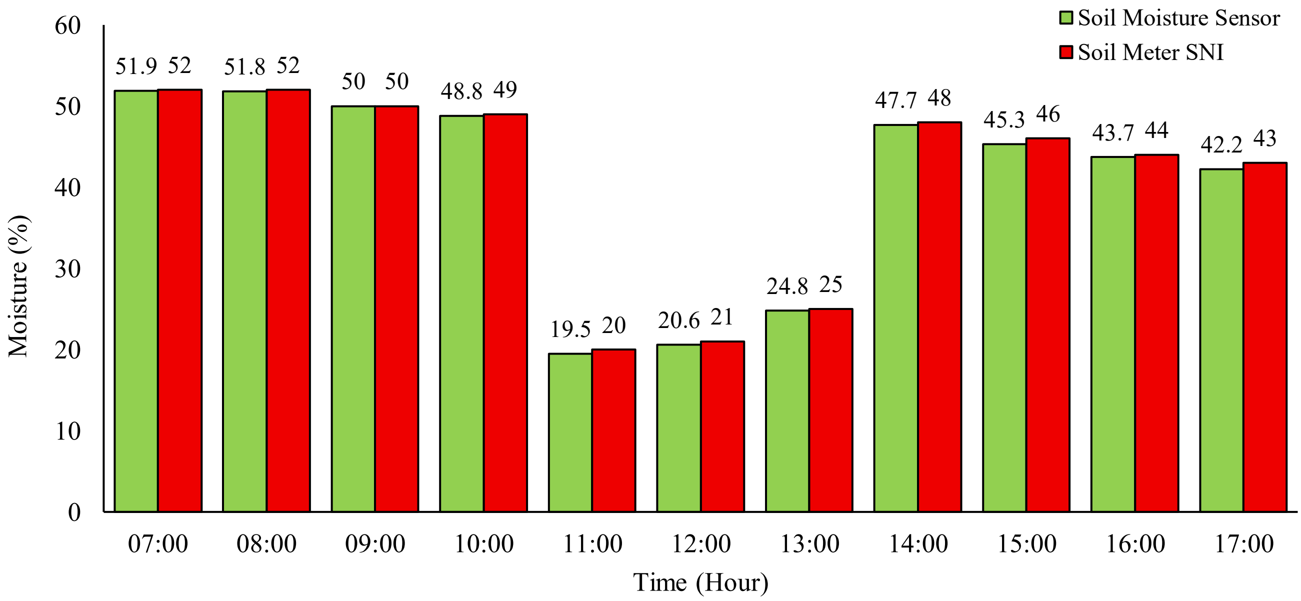


**Figure 2.** Comparison of soil moisture values between sensors and conventional measuring instruments

Based on Figure 2, it can be seen that the soil moisture values measured by the YL-69 sensor and the Soil Meter show relatively similar values. The highest humidity occurs between 08:00 and 09:00, with values of around 50–52%, indicating that the soil is wet. It then begins to decrease between 11:00 and 12:00, with values of around 19–21%, indicating that the soil is starting to dry. This is because the soil receives sunlight, which causes the temperature to increase [12]. After 13:00, humidity increases again to around 43–47% in the afternoon (14:00–17:00). This increase is attributed to the additional water content resulting from automatic watering [13][14]. The difference in measurement results between the two devices is relatively small (1–2%), indicating that the YL-69 sensor has a high level of accuracy and the results are comparable to those obtained using the Soil Meter. The graph shows that the YL-69 sensor is reliable in automatically monitoring changes in soil moisture, yielding consistent results compared to its comparison tool.

Based on Figure 2, it can be seen that the results of soil temperature measurements using the DS18B20 sensor and the Soil Meter show the exact and consistent change pattern throughout the observation period. Soil temperature increases from the morning (around 32–33°C) to reach its highest peak at 12:00, namely 37.0°C (DS18B20) and 37.5°C (Soil Meter). After that, the temperature begins to decrease gradually until the afternoon (at 17:00) to around 27–28°C. The difference in results between the two devices is minimal (±0.5°C), indicating that the DS18B20 sensor has a high level of accuracy and its measurement results are comparable to the Soil Meter. Data on error and accuracy values based on the results of soil moisture measurements are seen in Table 1.

**Table 1.** Error and accuracy values of soil moisture sensor testing

| Time (Hour) | Soil Moisture Sensor (%) | Soil Meter SNI (%) | Error (%) | Accuracy (%) | Automatic Watering |
|---|---|---|---|---|---|
| 07:00 | 51.9 | 52.0 | 0.192 | 99.808 | OFF |
| 08:00 | 51.8 | 52.0 | 0.385 | 99.615 | OFF |
| 09:00 | 50.0 | 50.0 | 0.000 | 100.000 | OFF |
| 10:00 | 48.8 | 49.0 | 0.408 | 99.592 | OFF |
| 11:00 | 19.5 | 20.0 | 2.500 | 97.500 | ON |
| 12:00 | 20.6 | 21.0 | 1.905 | 98.095 | ON |
| 13:00 | 24.8 | 25.0 | 0.800 | 99.200 | ON |
| 14:00 | 47.7 | 48.0 | 0.625 | 99.375 | OFF |
| 15:00 | 45.3 | 46.0 | 1.522 | 98.478 | OFF |
| 16:00 | 43.7 | 44.0 | 0.682 | 99.318 | OFF |
| 17:00 | 42.2 | 43.0 | 1.860 | 98.140 | OFF |
| Average | | | 0.989 | 99.011 | |

Based on the data in Table 1, it can be seen that the soil moisture values read by the YL-69 sensor have a minimal difference compared to those of the soil meter. Therefore, the highest error value was only 2.5% at 11:00, while the lowest error reached 0% at 9:00. The average error of the sensor readings compared to the reference device was only 0.989%, with an average accuracy level of 99.011%, indicating that the YL-69 sensor has very high accuracy in detecting soil moisture content. The lower the error value, the better the sensor performance, as it indicates that the sensor readings are closer to the actual value or reference value of the reference device [15]. Likewise, the higher the sensor accuracy value, the better the sensor performance, as it indicates that the sensor can read data with high accuracy relative to actual conditions [16].

Furthermore, as sunlight intensity increases toward midday, the air surface temperature rises, leading to increased evaporation. Consequently, soil moisture will continue to decrease unless it is corrected or replenished with water. Research shows that sunlight intensity has a significant impact on environmental temperature and climate elements (including humidity) and that sunlight intensity, soil temperature, and soil moisture are interrelated [17][18].

The automatic pump remains off when humidity is around 48–50% between 7:00 and 10:00 AM. Soil moisture drops dramatically to 19.5–24.8% between 11:00 and 13:00, indicating that the soil is starting to dry out due to increased soil temperature and water evaporation, prompting the automatic pump system to ON. After watering, the humidity level rises again in the afternoon (14:00–17:00) to around 42–47%, and the system automatically turns off the pump once the soil has returned to a sufficient moisture level.

These results demonstrate that the soil moisture sensor-based automatic watering system functions effectively, responsively, and stably. The sensor accurately measures soil moisture levels and sends signals to a microcontroller, which controls the pump according to pre-programmed thresholds. This automated process successfully maintains soil moisture levels within the ideal range for plant growth, thereby increasing water use efficiency and preventing soil conditions from becoming too dry or too wet [9][19].

Overall, these tests demonstrate that the YL-69 sensor performs very well and is suitable for use in an IoT-based automatic plant watering system. With an average accuracy of 99.011%, this sensor has been proven to provide stable and consistent measurement results that align with conventional benchmarks. These results also demonstrate that the developed automation system operates according to its logic for intelligent and efficient soil moisture control.

From the analysis results, it can be concluded that the 3-In YL-69 soil moisture sensor demonstrates highly accurate capability in measuring soil water content with an average accuracy rate of 99.011% and a minimal error of 0.989%. The automatic watering system built can respond to changes in soil conditions appropriately, where the water pump will be "ON" when the soil is dry and "OFF" when the soil is sufficiently moist. Thus, the YL-69 sensor-based system is considered adequate, efficient, and feasible for implementation in IoT-based innovative agriculture applications to maintain soil moisture in ideal conditions for plant growth. Furthermore, the data from the soil temperature sensor test results are seen in Figure 3.

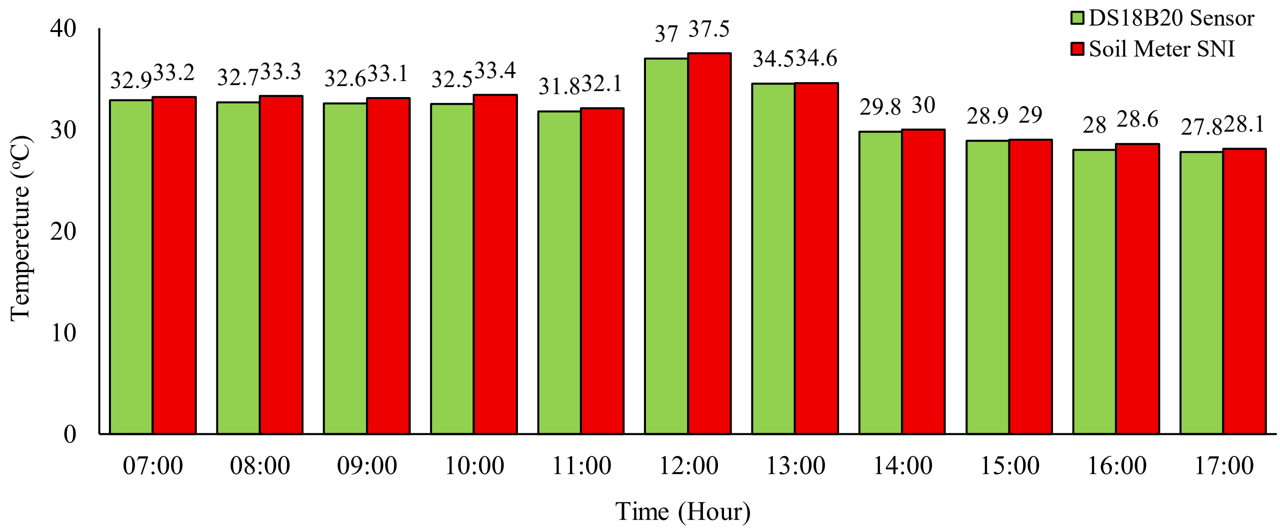

**Figure 3.** Comparison of temperature values between sensors and conventional measuring instruments

Figure 3 shows the measurement results indicating that soil temperature experienced a reasonable and logical change during the test period. In the morning (7:00–10:00), the soil temperature ranged from 32.5 to 33.4°C, indicating that the soil temperature began to increase due to exposure to sunlight. The higher the intensity of sunlight towards noon, the higher the soil temperature due to the greater heat energy absorbed by the soil surface, resulting in a tendency for soil water content to decrease due to increased evaporation rates [12]. This finding is consistent with research that indicates a direct relationship between increasing solar radiation intensity and both increasing soil temperature and decreasing soil moisture [18]. Toward noon (12:00), the soil temperature reached its highest point, at 37°C, due to significant increases in sunlight intensity and ambient temperature. After 13:00, the soil temperature began to decrease gradually, reaching 27.8°C at 17:00, as sunlight intensity decreased and soil moisture increased due to the automatic watering process that had occurred previously. Data on error and accuracy values based on the results of the soil moisture measurements are shown in Table 2.

**Table 2.** Error values and accuracy of soil temperature sensor testing

| Time (Hour) | DS18B20 Sensor (°C) | Soil Meter SNI (°C) | Error (%) | Accuracy (%) |
|---|---|---|---|---|
| 07:00 | 32.9 | 33.2 | 0.904 | 99.096 |
| 08:00 | 32.7 | 33.3 | 1.802 | 98.198 |
| 09:00 | 32.6 | 33.1 | 1.511 | 98.489 |
| 10:00 | 32.5 | 33.4 | 2.695 | 97.305 |
| 11:00 | 31.8 | 32.1 | 0.935 | 99.065 |
| 12:00 | 37.0 | 37.5 | 1.333 | 98.667 |
| 13:00 | 34.5 | 34.6 | 0.289 | 99.711 |
| 14:00 | 29.8 | 30.0 | 0.667 | 99.333 |
| 15:00 | 28.9 | 29.0 | 0.345 | 99.655 |
| 16:00 | 28.0 | 28.6 | 2.098 | 97.902 |
| 17:00 | 27.8 | 28.1 | 1.068 | 98.932 |
| Average | | | 1.240 | 98.760 |

Based on the measurement data in Table 2, it can be seen that the soil temperature values measured by the DS18B20 sensor have very little difference compared to those obtained using the Soil Meter comparison tool. The resulting error value falls within the range of 0.289% to 2.695%, with an average error of 1.240%. Meanwhile, the average accuracy value of the DS18B20 sensor reaches 98.760%, indicating that this sensor has a very high level of reliability and precision in detecting soil temperature in real time. The lower the error value, the better the sensor performance because it indicates the sensor's ability to read data close to the actual value from the comparison tool [20]. Likewise, the higher the sensor accuracy level, the better and more reliable the sensor is for use in an IoT-based soil temperature measurement system [21].

The slight difference between the values generated by the DS18B20 sensor and the Soil Meter indicates that this digital sensor is capable of providing stable, accurate, and responsive readings to changes in soil temperature. The very low error value indicates that the sensor calibration process has run well, and the sensor can be relied upon for long-term soil temperature monitoring in IoT-based automation systems. In addition, slight variations in the reading results are likely caused by differences in measurement points, sensor placement depth, and slightly different response times between digital and analogue devices. These results also show a direct relationship between soil temperature and soil moisture, where an increase in soil temperature tends to decrease soil moisture due to water evaporation in the soil. Conversely, a decrease in soil temperature increases soil moisture because water is no longer evaporated as much.

This relationship demonstrates that the DS18B20 sensor is not only crucial for monitoring temperature but also plays a vital role in supporting automatic watering systems, enabling them to adjust the time and duration of watering based on dynamic environmental conditions. With an average accuracy of 98.760%, it can be concluded that the DS18B20 sensor has excellent performance and is suitable for use in an IoT-based soil temperature monitoring system. This sensor provides valid and stable data, supporting an automatic soil moisture control system that maintains ideal soil conditions for plant growth.

Overall, both sensors demonstrated excellent and consistent performance throughout the observation period. The data obtained indicate that the relationship between temperature and soil moisture is inversely proportional: as temperature increases, soil moisture decreases, and as temperature decreases, soil moisture increases [18]. This relationship occurs because an increase in temperature causes an increase in the rate of soil water evaporation and plant transpiration, thereby decreasing the soil water content. Meanwhile, as the temperature decreases, the evaporation process slows down, and the soil reabsorbs moisture from the environment [12]. With the high level of accuracy of both sensors (YL-69 and DS18B20), the developed IoT-based automatic watering system is considered to function optimally. It can maintain ideal soil conditions for plant growth throughout the day, in accordance with the principle of automatic humidity control based on sensor data [22]. The application of IoT in modern agriculture can serve as a practical learning medium to train trainees in designing, calibrating, and operating sensors, as well as understanding the relationship between environmental data and automated decision-making. This system can then be applied in agricultural technology education and vocational training programs.

## Conclusion

Based on the test results, the IoT-based automatic watering system, utilizing the YL-69 soil moisture sensor and the DS18B20 soil temperature sensor, has been proven to work effectively and responsively. The YL-69 moisture sensor boasts high accuracy, with an average error of 0.989% and an accuracy rate of 99.011%. This enables it to monitor soil moisture stably and control the automatic pump accordingly, based on soil conditions. The DS18B20 temperature sensor also exhibits excellent performance, with an average error of 1.240% and an accuracy of 98.760%. It accurately detects daily changes in soil temperature, where an increase in temperature is accompanied by a decrease in soil moisture, and vice versa. This inverse relationship between temperature and soil moisture strengthens the reliability of the system in controlling automatic watering based on real field conditions. This system has been proven to be effective, efficient, and feasible for implementation in IoT-based smart agriculture, enabling the maintenance of ideal soil moisture for plant growth. The application of IoT in modern agriculture can serve as a practical learning medium to train trainees in designing, calibrating, and operating sensors, as well as understanding the relationship between environmental data and automated decision-making. This system can then be applied in agricultural technology education and vocational training programs.

**Author's Contributions**

Susilo Yudoyono: Conceptualization, writing-original draft preparation, methodology; Dewa Gede Eka Setiawan: Conceptualization, methodology; Muhammad Yunus: Curation, writing-original draft preparation, writing-review and editing; Muh. Fachrul Latief: Methodology; Icha Untari Meidji: Formal analysis, validation.

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