



## SMART GARDEN ONLINE AUTOMATIC PLANT WATERING - IOT CONTROL AND MONITORING TRAINER

Muhammad Hasan Basri <sup>1</sup>, Saiful Akbar <sup>2</sup>

<sup>1</sup> Electrical Engineering Department of Nurul Jadid University, Paiton Probolinggo, Indonesia

<sup>2</sup> Mathematics Study Program, Abdurachman Saleh University, Situbondo, Indonesia

Email: [hasanmohammadbasri83@gmail.com](mailto:hasanmohammadbasri83@gmail.com) <sup>1</sup>, [akbarsaiful920@gmail.com](mailto:akbarsaiful920@gmail.com) <sup>2</sup>

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### Abstract :

*This research discusses the implementation of an ESP32-based Smart Garden system consisting of two main components, namely a sensor module and a controller module. The sensor module uses a DHT11 sensor to record air temperature and humidity data periodically every hour from 7:00 to 19:00 WIB for seven days. The measurement results show a temperature pattern that increases from morning to noon and decreases in the afternoon, while humidity shows an inverse pattern. The average highest temperature recorded was 29.92 °C on Monday and the lowest temperature was 29.01 °C on Wednesday, with daily humidity ranging from 60.31% to 61.15%. Meanwhile, the controller module functions to regulate plant watering in three operating modes: manual, timer, and automatic. Manual mode allows direct control by the user via buttons, timer mode regulates automatic watering based on a schedule stored in the EEPROM and synchronized with the NTP time, while automatic mode uses fuzzy logic to water based on environmental conditions. The system is also equipped with a battery voltage monitoring feature and a status indicator on the LCD. The test results show that all system components work in an integrated, stable manner, and are able to support intelligent plant watering based on real environmental conditions.*

**Keywords:** Smart Garden, ESP32, DHT11, automatic watering, IoT, temperature and humidity sensor, controller, NTP, environmental monitoring.

### INTRODUCTION

In everyday life, plants play a vital role for humans and the environment, serving as a food source, as a source of greenery, and as an aesthetic aid (Kurniawan, 2021). One of the main challenges in caring for plants is ensuring adequate water supply for optimal growth. Irregular watering, whether due to busyness, forgetfulness, or a lack of understanding of plant needs, can cause stress, wilting, and even death (Sari & Lestari, 2022). Conversely, overwatering can lead to water waste, waterlogging, and root damage due to excess water (Westari & Ilman, 2024).

Drought-induced plant conditions inhibit photosynthesis due to reduced water content in plant tissues (Farhani & Purwanto, 2024). Impaired photosynthesis reduces the plant's ability to produce energy for growth and development, ultimately leading to yellowing of the leaves and plant death (Najid & Omar, 2024). Furthermore, excess water around the roots can cause rot, reduce oxygen levels in the soil, and trigger the growth of pathogenic microorganisms that damage plants (Alsammak & Mohammed, 2022).



Soil moisture is a crucial parameter in irrigation systems because it directly impacts water availability for plants. Soil that is too dry can cause water stress in plants, hindering photosynthesis, growth, and yield. Conversely, soil that is too wet can also cause root rot due to lack of oxygen. Ideally, soil moisture should be maintained at 50%-70% of field capacity, depending on the plant species and growing medium used (Zotarelli et al., 2015). Air temperature also plays a crucial role in plant growth. Temperatures that are too high ( $>35^{\circ}\text{C}$ ) can increase the rate of *evapotranspiration*, accelerating water evaporation from leaves and soil, thus increasing plant water requirements. Temperatures that are too low ( $<15^{\circ}\text{C}$ ) can inhibit metabolism and photosynthesis. Therefore, real-time temperature monitoring helps determine appropriate irrigation needs, especially in *greenhouse environments* with their own microclimate characteristics (Taiz et al., 2015).

With the development of technology, particularly in the *Internet of Things* (IoT), plant watering can be automated to be more efficient and tailored to needs. IoT enables the integration of electronic devices with the internet, allowing users to monitor and control remotely (Najid & Omar, 2024). By utilizing sensors such as the DHT11 and soil moisture sensors, as well as microcontrollers such as the ESP32, IoT-based plant watering systems can adjust watering times and intensity based on real-time environmental data (Westari & Ilman, 2024). The use of NTP provides additional reliability in time-based automatic watering systems. When the RTC DS1307 fails or loses backup battery power, the system can still obtain accurate time from the NTP server. The combination of RTC and NTP creates a redundant time system, ensuring that watering continues on schedule even if there is a disruption to one of the time sources. Furthermore, the implementation of NTP increases flexibility in time zone adjustments and avoids time errors caused by manual settings (Yuliyanto & Rahman, 2023).

ESP-NOW is a wireless communication protocol developed by Espressif that allows ESP32 devices to communicate directly with each other without the need for a Wi-Fi connection. This protocol uses MAC addresses for identification and can transmit data with low latency. One of ESP-NOW's advantages is its energy efficiency. Because it does not require a continuously active Wi-Fi connection, the device's power consumption is lower, making it suitable for battery-based remote sensor applications. One-way or two-way communication systems can be created by setting the device's role as a data sender or receiver (Wibowo & Fathurrahman, 2023).

Network Time Protocol (NTP) is a network protocol used to synchronize time between devices on a computer network. NTP allows devices to obtain time information from geographically distributed global time servers. This protocol is designed to maintain time accuracy down to the millisecond and is widely used in systems that require high-precision timing, such as monitoring systems, industrial control, and IoT communications (Mills, 2020).

Although IoT-based automatic watering systems have been widely developed, their implementation remains challenging. Common obstacles include a lack of user understanding of IoT-based systems, limited resources, and the need for practical training (Purnama et al., 2023). Therefore, a learning tool

(trainer ) is needed to help students understand the basic concepts of IoT systems and their applications in smart agriculture.

Based on the background that has been described, the problem formulation in this research is as follows: How to design and build an IoT-based automatic plant watering system that can be monitored online, How to integrate two wireless modules (sensor and controller) with one-way communication using the ESP-NOW protocol, and How to implement three operating modes (Manual, Timer, and Automatic based on soil moisture) in the plant watering control system.

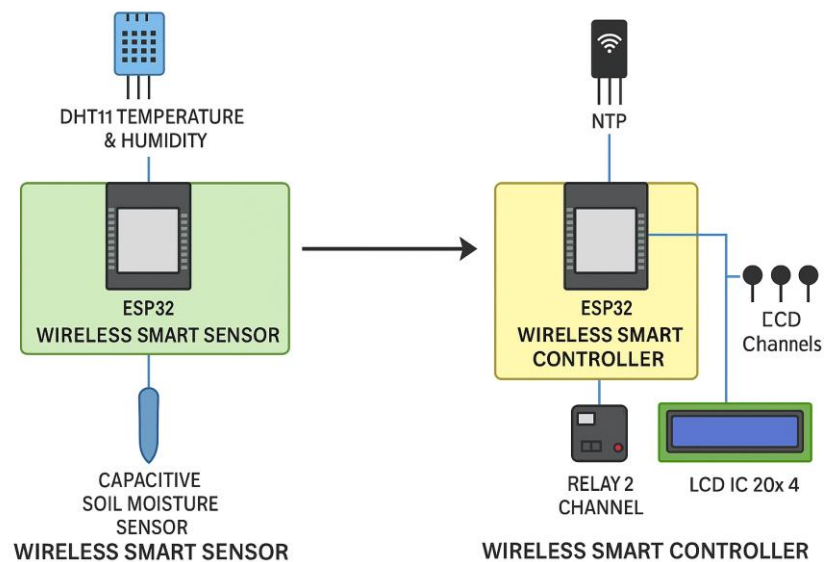
## RESEARCH METHOD

### Development/Design Model

*embedded* system engineering approach that is designed in a modular and integrated manner. The system design is divided into two main modules: the *Wireless Smart Sensor Module* and the *Wireless Smart Controller Module* , which communicate with each other using the ESP-NOW protocol. The development process starts from requirements analysis, hardware and software design, to system testing and evaluation.

#### 1. System Block Diagram

The general system block diagram can be seen in Figure 1. The sensor module consists of an ESP32, a DHT11 sensor, and a capacitive soil moisture sensor. The controller module contains an ESP32, RTC, relay, 20x4 I2C LCD, push buttons, and a battery monitoring system. Both modules are connected wirelessly using ESP-NOW.



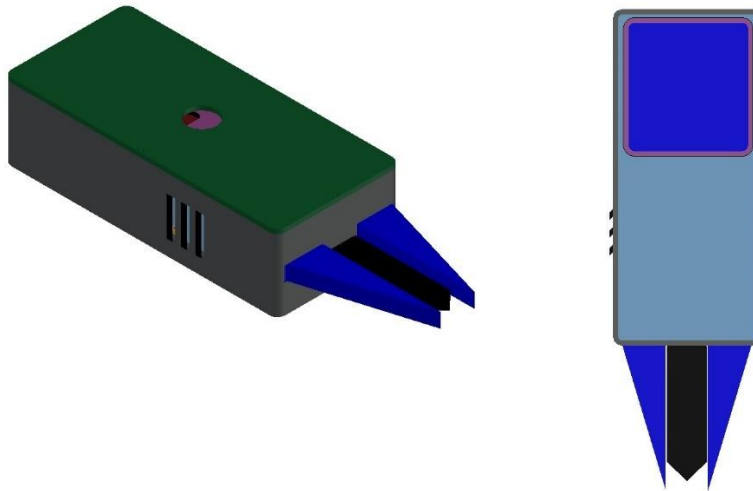
**Figure 1** Tool Block Diagram.

From Figure 1, the block diagram of the IoT-based automatic watering system above illustrates the main architecture of the designed system.

#### 2. Smart Sensor Module Chasing Design

The casing design for the Smart Sensor Module aims to protect electronic

components from external environmental conditions such as rain, dust, and direct sunlight. This casing was designed using AutoCAD software in the form of a three-dimensional isometric drawing to facilitate visualization of the dimensions and position of each component inside. This design drawing is shown in Figure 2, which shows an isometric view of the Smart Sensor Module casing.



**Figure 2** Smart sensor module.

Once the design was complete, the casing model was exported in 3D file format (STL) and then printed using a 3D printer using lightweight and weather-resistant PLA (Polylactic Acid). The printing process was carried out with a layer thickness of 0.2 mm and an infill of approximately 20% to maintain strength and material efficiency.

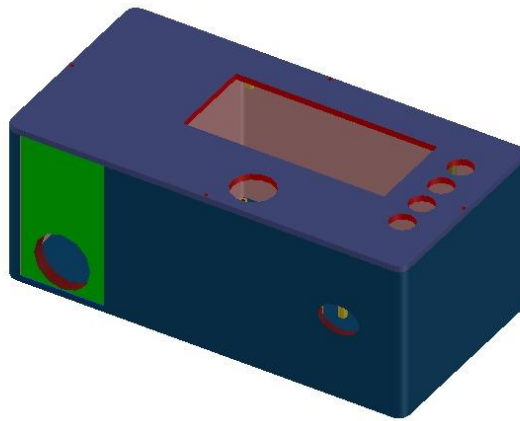
### 3. Smart Controller Module Chasing Design

The chassis for the Smart Controller Module is designed with user accessibility to the input-output interface in mind, as well as good air circulation to prevent overheating.

This casing has several compartments and openings, namely:

- The lid has a 20x4 LCD.
- 4 push buttons.
- Inner space for ESP32, MOSFET driver for valve driver.
- Valve connector hole and power source.

The visual design of this casing is depicted in Figure 3, which shows an isometric view of the Smart Controller Module casing designed in AutoCAD.



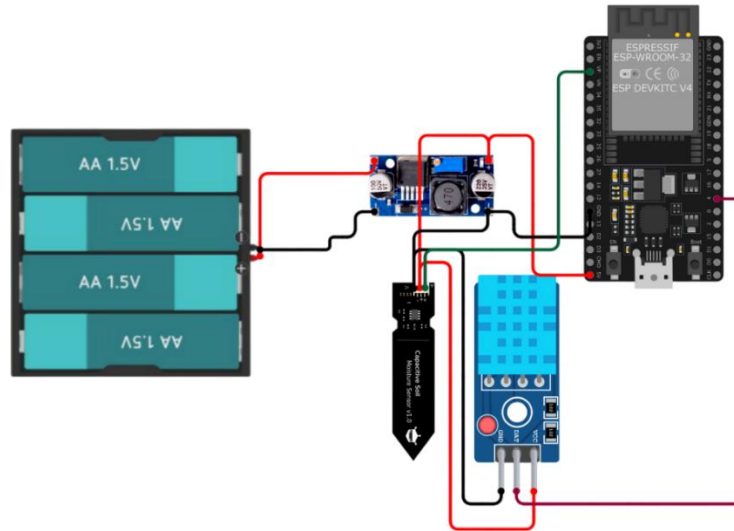
**Figure 3.** *Smart controller module design.*

#### **4. Sensor Module Circuit Design**

The circuit above is a wireless sensor module that measures environmental conditions around plants, such as air temperature, humidity, and soil moisture. Power comes from four 1.5V AAA batteries, converted to 5V using a step-down buck converter (e.g., AMS1117 or similar) to meet the ESP32's voltage requirements.

The DHT11 sensor is used to measure temperature and humidity, while the capacitive soil moisture sensor measures soil moisture. Both sensors are connected to an ESP32, the main brain, which manages data readings and sends them wirelessly via the ESP-NOW protocol to the controller module. This module operates independently and has no display, but it continuously sends sensor data periodically to another ESP32, which serves as the main controller.

The red wire indicates the voltage line (VCC), black for ground (GND), and green or other colors for data signals from the sensor to the ESP32. With this design, the system allows for real-time monitoring of plant conditions wirelessly, is power efficient, and is suitable for Internet of Things (IoT) implementations.



**Figure 4.** Smart sensor electronic module design.

### 5. Controller Module Circuit Design

The Smart Controller electronic module design is the control center of an IoT-based automatic plant watering system. This module uses an ESP32 microcontroller as the main processing unit that functions to receive sensor data from the Smart Sensor module via ESP-NOW communication, as well as run system control logic based on the selected working mode (automatic, manual, or timer).

The local user interface consists of a 20x4 I2C LCD displaying temperature, humidity, soil moisture, current time (from NTP), and valve status. Menu navigation and parameter setting are performed using four push buttons: one for entering the setting mode, increasing/decreasing the value, and the OK/Run button.

To control the 12V solenoid valve, the IRF4905 MOSFET driver is used, capable of handling high currents efficiently and safely. This module also connects to a local WiFi network and can be accessed via a web dashboard for remote monitoring and control.

This design was designed with modularity, power supply stability, and ease of reprogramming using the Arduino IDE in mind. The module is also designed to support casing printing using AutoCAD designs and can be manufactured with a 3D printer.

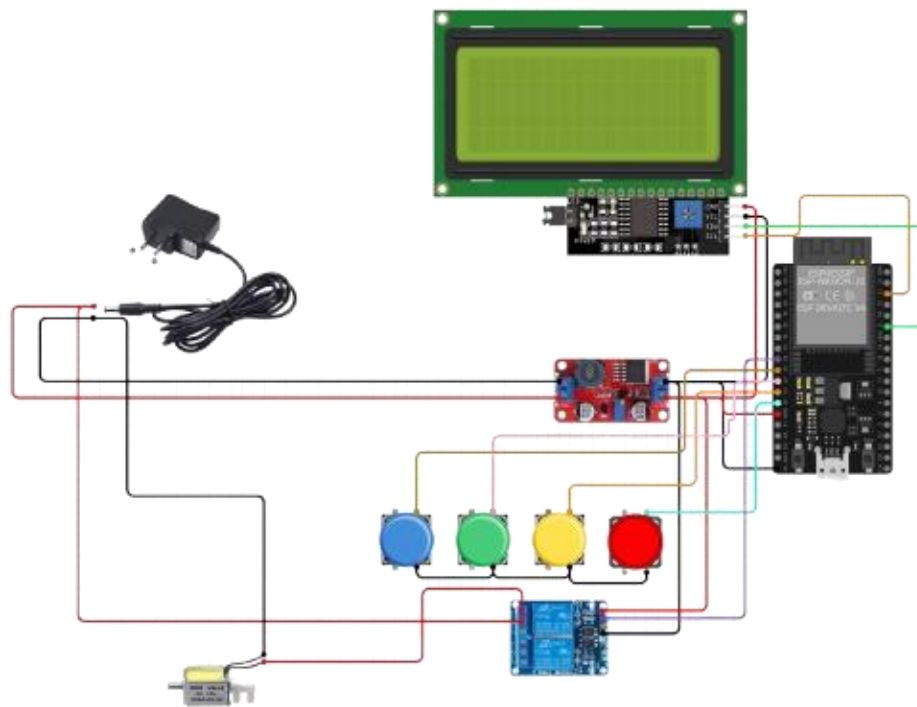


Figure 5. Smart controller electronic module design.

## FINDINGS AND DISCUSSION

### 1. Implementation and Results of Smart Sensor Module Data Collection

Data from DHT11 sensor and soil moisture sensor readings were collected 13 times in one day (Monday), namely on July 7, 2025 in Paiton, from 7:00 AM to 7:00 PM WIB. Data collection was carried out every hour to test the stability and reliability of the Smart Sensor module in reading and sending environmental data periodically.

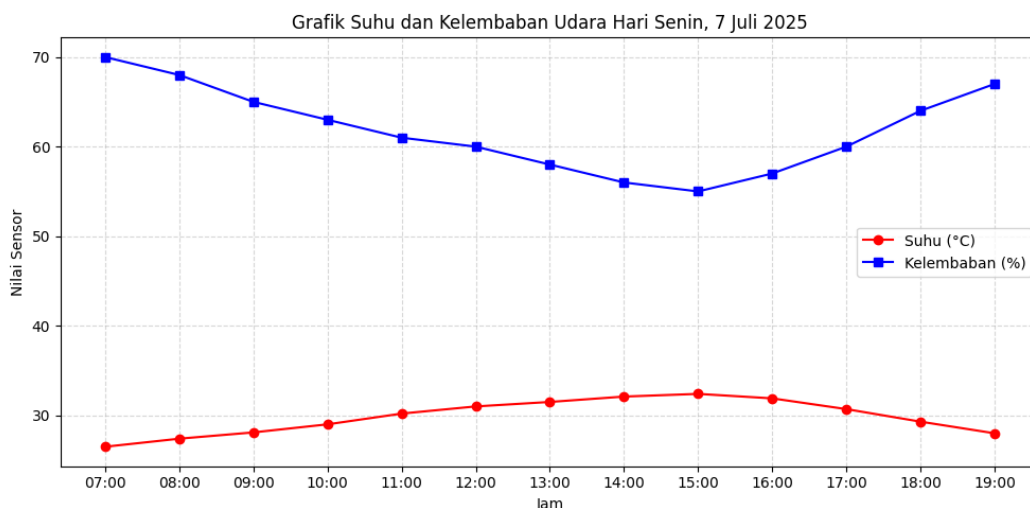
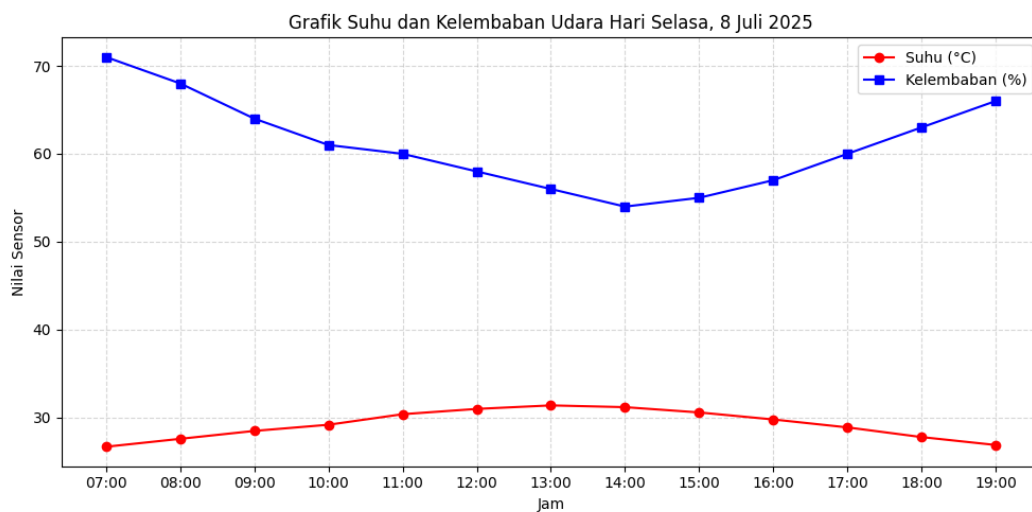


Figure 6. Temperature and Humidity Graph for Monday, July 7, 2025.

The graph of sensor readings on Monday shows a daily pattern consistent with tropical climate conditions. The temperature gradually increased from 7:00 a.m. WIB (Western Indonesian Time) and reached a peak of 32.4°C at 3:00

p.m. WIB (Western Indonesian Time), before decreasing again until the evening. Conversely, humidity decreased as the temperature increased, reaching a low of 55% at the same time, then began to rise again as the temperature decreased. This pattern demonstrates that the Smart Sensor module successfully recorded environmental data accurately and in real time, reflecting actual conditions, which are crucial for making decisions about automatic plant watering.

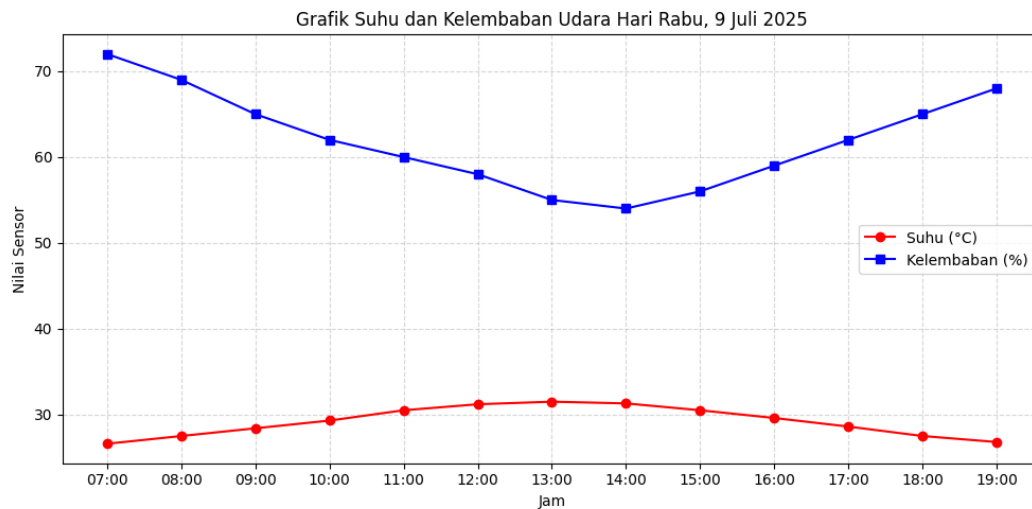
On Tuesday, temperatures showed a steady increase from morning to peak at 31.4 °C at 1:00 PM WIB. Afterward, temperatures gradually decreased until evening. Humidity decreased as the temperature rose, starting to rise again after 3:00 PM WIB, reaching 55%. This pattern is consistent with tropical weather trends, indicating that the sensor system is functioning normally in monitoring temperature and humidity fluctuations.



**Figure 7.** Air Temperature and Humidity Graph Tuesday, July 8, 2025.

The graph of sensor readings on Tuesday, July 8, 2025, shows temperature and humidity trends consistent with daily climate characteristics. The air temperature gradually increased from morning to 26.7°C at 07:00 WIB and reached a peak of 31.4 °C at 1:00 PM WIB. After that, the temperature began to decrease slowly until it reached 26.9 °C at 7:00 PM WIB. Conversely, air humidity decreased as the temperature increased, from 71% in the morning to a low of 54% at 2:00 PM WIB, then increased again towards evening. This pattern shows an inverse relationship between temperature and humidity, and confirms that the *Smart Sensor module* is able to accurately detect and record environmental changes, which is very useful as a basis for decision-making in an IoT-based automatic watering system.

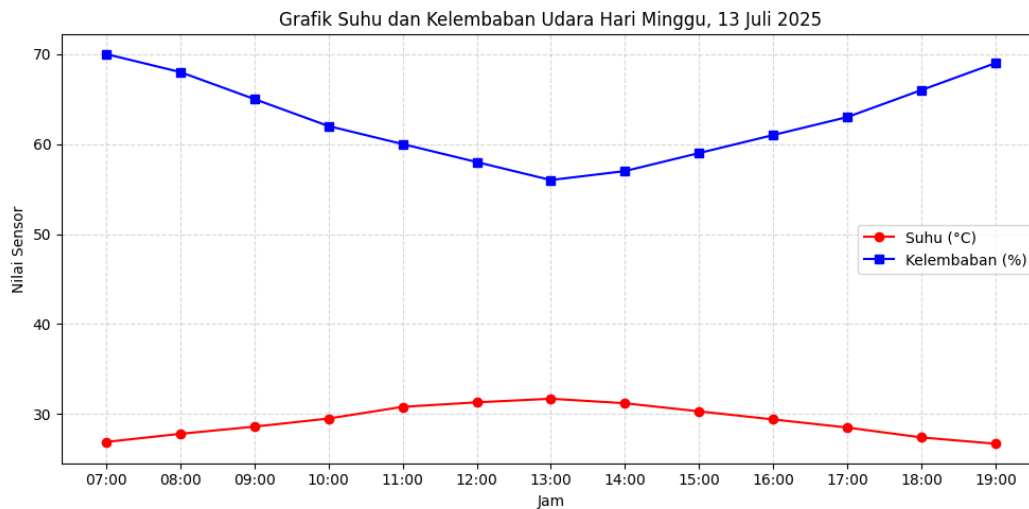
On Tuesday, temperatures showed a steady increase from morning to peak at 31.5 °C at 1:00 PM WIB. Afterward, temperatures gradually decreased until evening. Humidity decreased as the temperature rose, and began to rise again after 2:00 PM WIB, reaching 53%. This pattern is consistent with tropical weather trends, indicating that the sensor system is functioning normally in monitoring temperature and humidity fluctuations.



**Figure 8.** Air Temperature and Humidity Graph for Wednesday, July 9, 2025.

The graph of sensor readings on Wednesday, July 9, 2025, shows a steady increase in temperature since the morning, starting from 26.6 °C at 07:00 WIB and reached a maximum point of 31.5 °C at 1:00 PM WIB. After that, the temperature began to decrease gradually until the evening. Air humidity decreased as the temperature increased, from 72% in the morning to a low of 54% at 2:00 PM WIB, then increased again as the temperature decreased. This graph pattern again shows an inverse relationship between temperature and humidity, and proves that the sensor works consistently and responsively in recording dynamic environmental conditions throughout the day. These results support the effectiveness of the system as a learning medium and IoT-based environmental control.

On Tuesday, temperatures showed a steady increase from morning to peak at 31.5 °C at 1:00 PM WIB. Afterward, temperatures gradually decreased until evening. Humidity decreased as the temperature rose, and began to rise again after 2:00 PM WIB, reaching 55%. This pattern is consistent with tropical weather trends, indicating that the sensor system is functioning normally in monitoring temperature and humidity fluctuations.



**Figure 9.** Temperature and Humidity Graph for Sunday, July 13, 2025.

The sensor reading graph on Sunday, July 13, 2025, shows that the air temperature increased from 26.9 ° C at 07:00 WIB and reached its highest point of 31.7 ° C at 1:00 PM WIB, before gradually decreasing until the evening. Meanwhile, humidity decreased from 70% in the morning to a low of 56% at 1:00 PM WIB, before rising again to 69% at 7:00 PM WIB. This graph shows a consistent daily pattern, as in previous days, where temperature and humidity have an inverse relationship. This indicates that the sensor system is functioning stably and accurately in monitoring environmental dynamics, and is capable of providing reliable real-time data in an automated decision-making system for IoT-based plant watering.

**2. Implementation and Results of Data Collection of Controller Module**

The following is the test result data for the Smart Controller Module based on 3 operating modes (Manual, Timer, and Automatic) for 1 week:

1. In Manual Mode

In manual mode, the user turns the valve on and off manually using the PB4 button.

**Table 1.** Manual Mode Test Results for 1 Week.

No	Day	ON Time	OFF Time	Duration (minutes)
1	Monday	08:10	08:15	5
2	Tuesday	07:50	08:00	10
3	Wednesday	08:20	08:26	6
4	Thursday	08:05	08:15	10
5	Friday	08:12	08:18	6
6	Saturday	08:00	08:10	10
7	Sunday	07:55	08:05	10

2. In Timer Mode

This mode uses the automatic watering time setpoint at a specified hour.

**Table 2.** Timer Mode (NTP) Test Results for 1 Week.

No	Day	ON Time (Morning)	Duration	ON Time (Day)	Duration	ON Time (Night)	Duration
1	Monday	05:30	5 minutes	13:00	5 minutes	18:30	5 minutes
2	Tuesday	05:30	5 minutes	13:00	5 minutes	18:30	5 minutes
3	Wednesday	05:30	5 minutes	13:00	5 minutes	18:30	5 minutes
4	Thursday	05:30	5 minutes	13:00	5 minutes	18:30	5 minutes
5	Friday	05:30	5 minutes	13:00	5 minutes	18:30	5 minutes
6	Saturday	05:30	5 minutes	13:00	5 minutes	18:30	5 minutes
7	Sunday	05:30	5 minutes	13:00	5 minutes	18:30	5 minutes

### 3. In Automatic Mode

This mode relies on the results of automatic logic calculations from temperature, air humidity, and soil moisture sensors to determine the duration of watering.

**Table 3.** Results of Auto Mode Testing for 1 Week.

No	Day	Active Time	Duration (minutes)	Information
1	Monday	13:05	4	Dry soil, high temperature
2	Tuesday	13:10	5	Soil is very dry
3	Wednesday	13:07	3	The soil is slightly damp
4	Thursday	13:11	6	Very dry & hot conditions
5	Friday	13:06	2	Moderate temperature, fairly wet soil
6	Saturday	13:08	5	Dry soil & high temperature
7	Sunday	13:03	4	Low air humidity

This section analyzes the results obtained from the implementation of the ESP32-based Smart Garden system. The discussion focuses on interpreting data collected from the sensor and controller modules, as well as

evaluating system performance based on each operating mode (manual, timer, and automatic). The results are compared with theory and previous research to determine the extent to which this system works effectively and efficiently in automatically regulating plant watering.

### 3. Discussion of Sensor Module Data

The Smart Sensor Module using ESP32 and DHT11 sensor has successfully recorded air temperature and humidity data from Monday to Sunday periodically every hour starting at 07.00 to 19.00 WIB. The results of data collection show that the air temperature tends to increase from morning to noon, then decreases towards evening and night. The average highest temperature was recorded on Monday at 29.92 °C, while the average lowest temperature occurred on Wednesday at 29.01 °C. Meanwhile, air humidity shows a pattern that is inversely proportional to temperature, namely decreasing when the temperature increases and increasing again when the temperature begins to decrease, with an average daily humidity ranging from 60.31% to 61.15%.

The graph of average temperature and humidity over seven days illustrates that the sensor system is able to detect environmental changes consistently and accurately. These values also reflect the tropical climate conditions common in Indonesia, where days are hotter and drier, while mornings and evenings are cooler and more humid. This pattern is highly relevant in determining the need for automatic plant watering based on actual environmental conditions. Therefore, it can be concluded that the Smart Sensor module has functioned well in monitoring temperature and humidity parameters as a basis for decision-making in the automatic watering system. This data can also be used as learning material in understanding the working principles of IoT-based monitoring systems.

### 4. Discussion of Controller Module Data

The controller module acts as the control center for the automatic watering system. Based on test data from one week of three operating modes (manual, timer, and automatic), it appears that the system can adjust the actuator (valve) behavior according to programming logic and user-defined parameters. In manual mode, watering is controlled directly via the push button (PB4) without considering time or environmental conditions. Test results show that the valve only activates when the user actively presses the button. This mode operates responsively and stably, suitable for flexible watering by the user.

In timer mode, watering is performed automatically at certain times (morning, afternoon, evening) based on the set hour and minute setpoints. Testing shows that the system successfully activates the valve at the correct time according to the EEPROM settings, and turns off the valve according to the set duration. This demonstrates the successful integration between NTP time and load control. In automatic mode, the system will water if the environmental conditions are considered dry or hot simultaneously. From the test results, it is clear that the system works adaptively to environmental conditions and can determine the watering duration dynamically. This

duration value is displayed on the LCD, providing transparency to the system's actions. These results indicate that the fuzzy algorithm successfully mimics human decision-making in a simple yet effective way. In addition, the battery status monitoring and low-voltage load disconnection features function well. When the battery voltage drops below 3.3V, the system turns off the load to protect the battery, which is indicated by the "BAT LOW Load OFF" indicator on the LCD. Overall, the controller system has performed as designed: capable of executing control logic based on user input, time, and sensors in an integrated manner, as well as providing status information via the LCD and web dashboard.

## CONCLUSION

The ESP32-based Smart Garden system successfully recorded temperature and humidity data periodically using the DHT11 sensor, showing a consistent tropical climate pattern, with temperatures increasing from morning to noon and decreasing in the afternoon, The highest average temperature was recorded on Monday at 29.92 °C, while the lowest average temperature occurred on Wednesday at 29.01 °C, indicating a stable daily temperature variation, Air humidity showed a pattern that was inversely proportional to temperature, decreasing as the temperature rose and increasing as the temperature decreased, with a daily average ranging from 60.31% to 61.15%, The controller module worked well in three modes: Manual (direct control via buttons), Timer (automatic watering according to the EEPROM schedule and NTP time), and Automatic, and the system as a whole functioned stably and integrated, capable of making automatic watering decisions based on sensor data, time, and user input, as well as providing status information via the LCD and web dashboard.

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