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Development of a Smart IoT-Integrated Watering System for Moth Orchid (*Phalaenopsis amabilis*) Cultivation in the SMASHTHETIC Greenhouse

Ayu Ratna Permanasari*, Harita Nurwahyu Chamidy, Bevi Lidya, Ari Marlina, Endang Widiastuti, In Jumanda Kasdadi

Department of Chemical Engineering, Politeknik Negeri Bandung, Jawa Barat, Indonesia
***Corresponding author**: ayu.ratna@polban.ac.id

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Abstract
A greenhouse is a controlled environment designed to enhance plant productivity by regulating microclimatic conditions. However, in many greenhouse systems, the irrigation process is still performed manually, resulting in suboptimal water use efficiency and inconsistent watering schedules. The SMASHTHETIC greenhouse serves as a cultivation facility for the moth orchid (Phalaenopsis amabilis), which requires precise control of substrate moisture and ambient humidity to ensure optimal growth and flowering. This study aims to design and implement an automatic irrigation system based on Arduino and the Internet of Things (IoT) to improve irrigation efficiency in the SMASHTHETIC greenhouse. The system consists of a soil moisture sensor, Arduino microcontroller, Wi-Fi module (ESP8266/ESP32), and actuators such as a water pump and solenoid valve to regulate water flow. IoT integration enables real-time monitoring and remote control via web and smartphone applications. Experimental results show that the system automatically adjusts watering frequency and duration based on soil moisture data, providing convenience for users and reducing manual intervention. Therefore, this study demonstrates that the integration of Arduino and IoT technologies in greenhouse irrigation supports the development of smart agriculture practices that are more efficient, sustainable, and productive.
Keywords: *greenhouse, automatic irrigation, arduino, internet of things, irrigation efficiency, phalaenopsis amabilis*

Abstrak
Greenhouse atau rumah kaca merupakan lingkungan terkontrol yang dirancang untuk meningkatkan produktivitas tanaman melalui pengaturan kondisi mikroklimat. Namun, pada banyak sistem greenhouse, proses penyiraman masih dilakukan secara manual, sehingga efisiensi penggunaan air belum optimal dan jadwal penyiraman sering tidak konsisten. SMASHTHETIC greenhouse berfungsi sebagai fasilitas budidaya anggrek bulan (*Phalaenopsis amabilis*), yang membutuhkan pengendalian kelembapan media tanam dan kelembapan lingkungan secara presisi untuk memastikan pertumbuhan dan pembungaan yang optimal. Penelitian ini bertujuan untuk merancang dan mengimplementasikan sistem penyiraman otomatis berbasis Arduino dan Internet of Things (IoT) guna meningkatkan efisiensi irigasi di SMASHTHETIC greenhouse. Sistem ini terdiri dari sensor kelembapan tanah, mikrokontroler Arduino, modul Wi-Fi (ESP8266/ESP32), serta aktuator berupa pompa air dan katup solenoid untuk mengatur aliran air. Integrasi IoT memungkinkan pemantauan dan pengendalian secara real-time melalui aplikasi berbasis web maupun smartphone. Hasil pengujian menunjukkan bahwa sistem mampu menyesuaikan frekuensi dan durasi penyiraman secara otomatis berdasarkan data kelembapan tanah, sehingga memberikan kemudahan bagi pengguna dan mengurangi intervensi manual. Oleh karena itu, penelitian ini membuktikan bahwa integrasi teknologi Arduino dan IoT dalam sistem irigasi greenhouse dapat mendukung pengembangan praktik pertanian cerdas (smart agriculture) yang lebih efisien, berkelanjutan, dan produktif.
Kata Kunci: *greenhouse, penyiraman otomatis, arduino, internet of things, efisiensi irigasi, anggrek bulan*

1. Introduction

Phalaenopsis amabilis, commonly known as the moth orchid, is one of the most economically valuable ornamental plants and is widely cultivated in various greenhouses, including the SMASHTHETIC Greenhouse. The growth and flowering of this species are influenced by several environmental factors such as temperature ($Najikh\ et\ al.,$ 2018), humidity [1], [2], lighting [3], growing media, air circulation [4], irrigation [5], and root maintenance.

In terms of temperature, Phalaenopsis amabilis grows optimally at a stable condition, with ideal daytime temperatures ranging between 27–30 °C and nighttime temperatures between 21–24 °C [1]. Extreme temperature fluctuations or large differences between day and night temperatures can inhibit plant growth and delay flowering [1]. Humidity also plays a crucial role; this orchid thrives in environments with a relative humidity of 60–80%, which supports proper metabolism and water absorption. Unsuitable humidity levels, whether too low or too high, can cause physiological stress and increase the risk of fungal or bacterial infections [6].

Adequate lighting is essential for effective photosynthesis. Moth orchids require bright but indirect light, ideally with shading levels around 55–65%. Direct sunlight exposure can scorch the leaves, while insufficient light results in weak growth, elongated leaves, and reduced flowering capacity [3]. Another critical factor is the growing medium, which should be well-aerated and have good drainage. A mixture of coconut husk fiber, moss, and bark chips is commonly used to maintain healthy roots and prevent excessive moisture accumulation. Proper air circulation is also vital to maintain gas exchange and minimize fungal growth. Poor ventilation can lead to stagnant air conditions that promote diseases, while overly strong wind may cause dehydration and flower drop [4]. Moreover, irrigation management plays a key role in orchid care [7]. Phalaenopsis amabilis requires an environmental humidity of 60–80% and air temperature between 18–34 °C. Watering must be done carefully — avoiding both overwatering and underwatering — as inconsistent moisture levels can harm root health and reduce plant vigor [5].

The SMASHTHETIC Greenhouse was designed as a modern structure using galvanized hollow steel frames and solar flat roofing, which allows sufficient natural light penetration while maintaining durability and aesthetic appeal. This design provides advantages over conventional greenhouses and supports optimal photosynthetic activity [8], [9]. However, based on current conditions, irrigation in SMASHTHETIC Greenhouse is still performed manually. The conventional watering method presents several challenges, including:

1. Limited humidity control, as manual watering often disregards accurate soil moisture levels, leading to either overwatering or underwatering [10].
2. Inefficiency in water and labor usage, since irregular schedules cause water waste and increased labor costs [10].
3. Lack of remote monitoring and control, preventing real-time adjustments to changing environmental conditions; and
4. Absence of IoT-based automation, which limits data-driven decision-making for optimal orchid growth.

To address these challenges, the integration of Internet of Things (IoT) technology and Arduino microcontrollers offers an innovative solution for automated irrigation management in greenhouse environments [11], [12]. This technology enables soil moisture sensors to transmit data to the microcontroller, which then activates a water pump and solenoid valve according to plant needs. The system can be monitored and controlled remotely via a web-based or smartphone application, providing flexibility and real-time management.

Previous studies have shown that IoT-based irrigation systems effectively maintain optimal soil moisture levels and improve water-use efficiency. For instance, Nurahmi [13] demonstrated that an automatic irrigation system using an ESP8266 microcontroller and soil moisture sensors successfully maintained growth requirements for Phalaenopsis orchids [12], [14]. The integration of such systems supports the concept of smart and sustainable greenhouses, characterized by efficient, responsive, and data-driven management.

Based on this background, the present study focuses on the design and development of an Arduino- and IoT-based automatic irrigation system for SMASHTHETIC Greenhouse. The proposed system aims to maintain optimal soil moisture levels, enhance water efficiency, reduce dependency on manual labor, and enable remote monitoring and control through web and mobile applications [15].

2. Material and Methods

2.1. Research Location

This research was conducted at the **SMASHTHETIC Greenhouse**, a modern greenhouse constructed using galvanized hollow steel frames and *solar flat* roofing, designed to provide both functionality and aesthetic appeal, in Department of Chemical Engineering, Politeknik Negeri Bandung. The facility is dedicated to the cultivation of *Phalaenopsis amabilis* (moth orchids). At the beginning of the study, the greenhouse operated with a manual irrigation system, making it an ideal site for the development and implementation of an automatic IoT-based irrigation prototype.

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2.2. Materials and Equipment

The main biological material used in this study was the moth orchid (*Phalaenopsis amabilis*), planted in a mixture of coconut husk fiber, moss, and bark chips to ensure proper aeration and drainage. The tools and electronic components used in the design of the automatic irrigation system are listed in **Table 1**.

Table 1. The tools and electronic components used in the design of the automatic irrigation system

No	Component	Specification	Function
1	Arduino IDE	ATmega328P Microcontroller	Main control unit for system logic and decision-making
2	Soil Moisture Sensor (Capacitive Type)	Model YL-69 / FC-28	Measures soil moisture level in the growing medium
3	Wi-Fi Module ESP8266 / ESP32	2.4 GHz	Enables IoT connectivity for remote monitoring and control
4	DC Water Pump 12V	Flow rate: 2–3 L/min	Pumps water through the irrigation lines
5	Solenoid Valve 12V (NC Type)	Normally Closed	Controls water flow to the irrigation network
6	Relay Module (2-Channel)	5V DC	Switches the pump and valve automatically
7	Power Supply Adapter	12V / 5A	Provides stable power to the components
8	IoT Platform (Blynk / ThingSpeak)	Web and mobile interface	Enables real-time monitoring and control
9	PVC Piping	½ inch	Distributes water evenly to each plant pot

2.3. System Design and IoT Architecture

The automatic irrigation system follows a sensor–microcontroller–actuator–IoT architecture**. Figure 1** illustrates the system block diagram.

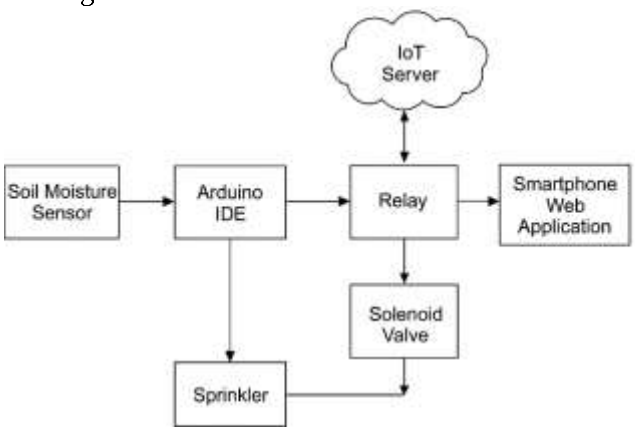

Figure 1. Block Diagram for automatic irrigation system

1. The soil moisture sensor measures the moisture content in the planting medium.
2. The data is transmitted to the Arduino IDE microcontroller, which compares the measured value with a predefined threshold (e.g., 30%).
3. When the moisture level falls below the threshold, the Arduino activates the relay, turning on the water pump and solenoid valve to start irrigation.
4. Once the desired moisture level is achieved, the system automatically stops the water flow.
5. Sensor data and system status are sent to the IoT server via the ESP8266/ESP32 module.
6. Users can monitor and control the system in *real time* through a web or smartphone application.

This system also supports manual override via the IoT platform, enabling users to start or stop watering remotely

2.4. Hardware Implementation

The hardware assembly consists of several interconnected subsystems:

- Sensor placement: The soil moisture sensor is embedded in the orchid's growing medium near the root zone to obtain accurate moisture readings.
- Control unit: The Arduino microcontroller and relay module are installed inside a waterproof enclosure to protect against humidity and water exposure.
- Water distribution system: The DC pump and solenoid valve are connected through PVC piping and mini sprinklers for even water dispersion.

- Power and communication: The ESP8266 module transmits data to the IoT platform via Wi-Fi connection.

All electrical connections were insulated and secured to ensure durability and safety under greenhouse humidity conditions.

2.5. Software Implementation

The control program was developed using the Arduino IDE with the C/C++ programming language. The workflow of the software includes:

1. Initialization: Setting up sensor, relay, and Wi-Fi module pins.
2. Data acquisition: Reading soil moisture values at specific intervals.
3. Decision-making: Comparing sensor readings with the threshold value (e.g., <30% activates watering).
4. Actuator control: Activating or deactivating the relay, pump, and solenoid valve based on logic results.
5. IoT integration: Sending real-time data to the IoT platform (Blynk/ThingSpeak) and enabling user commands via smartphone or web dashboard with domain github.io

A flowchart illustrating this process is shown in **Figure 2**.

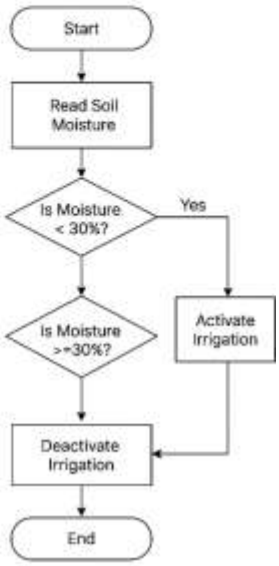

Figure 2. Flowchart of automatic control irrigation program

2.6. Testing and Evaluation Procedure

The developed system was tested to evaluate performance, reliability, and efficiency under different greenhouse conditions. The evaluation process included:

1. Sensor Calibration Test: Comparing sensor readings with reference measurements from a manual soil moisture tester.
2. Response Time Test: Measuring the delay between the detection of low moisture levels and the activation of irrigation.
3. Water Efficiency Test: Comparing the total water consumption between the automatic system and manual watering.
4. Remote Monitoring Test: Verifying data transmission stability and response consistency of IoT control through the application.

Each test was performed multiple times to ensure accuracy and consistency. The system's ability to maintain the optimal moisture range (60–80%) was observed over several weeks of operation.

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3. Results and Discussion

3.1 Circuit Design of IoT-Based Automatic Watering System

Figure 3 illustrates the wiring configuration of the IoT-based automatic watering system developed using the ESP32 microcontroller as the main control unit. The system integrates six soil moisture sensors (SOIL1–SOIL6) and a single-channel relay module connected to a water pump.

Each soil sensor is connected to separate analog input pins on the ESP32, allowing simultaneous monitoring of soil moisture in six different zones. This multi-point sensing approach ensures accurate detection of moisture variation across the growing media. The sensors receive power from the ESP32's 3.3 V and GND pins, ensuring stable readings and minimizing signal noise.

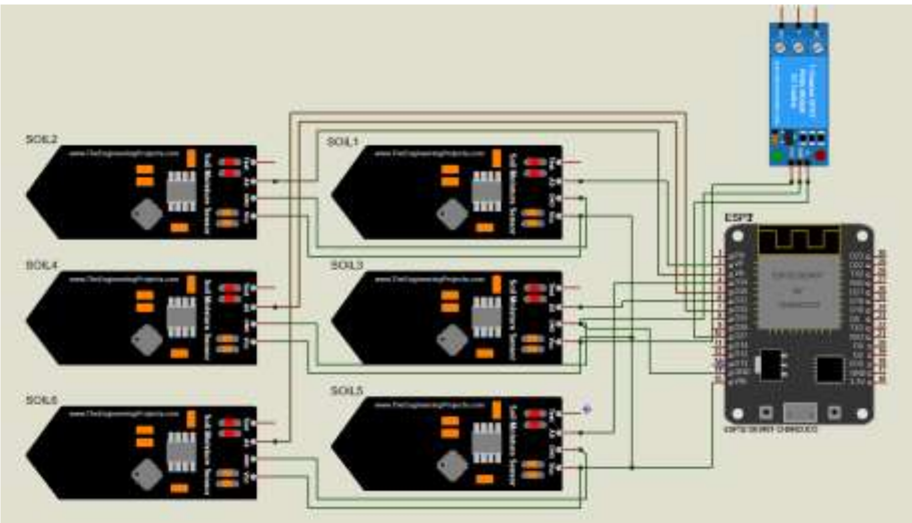

Figure 3. the wiring configuration of the IoT-based automatic watering system

The relay module functions as an electronic switch that controls the pump's power supply. When any sensor detects a moisture level below the preset threshold (e.g., 30%), the ESP32 sends a high digital signal to activate the relay, which turns on the water pump [16]. Once the soil moisture reaches the desired limit, the ESP32 outputs a low signal, deactivating the relay and stopping the pump. This setup enables fully automated irrigation control, significantly reducing manual intervention. The ESP32's built-in Wi-Fi connectivity allows real-time data transmission to an IoT platform or web dashboard, where soil moisture trends can be monitored and recorded [17].

Overall, the circuit design demonstrates the effectiveness of integrating ESP32 with soil moisture sensors for efficient, data-driven irrigation management. The multi-sensor configuration enhances precision in water distribution, making the system suitable for greenhouses, hydroponic systems, and precision agriculture applications.

3.2 Media Moisture Analysis

Figure 4 shows the variation of media moisture percentage over 14 days under two different watering systems: manual and automatic. The manual watering system exhibited a significant decline in soil moisture from 53% on the first day to around 10% by the fifth day, after which the moisture level remained nearly constant at that low level. This indicates that manual watering could not maintain consistent moisture in the growing medium, leading to excessively dry conditions that can inhibit orchid root respiration and nutrient uptake.

In contrast, the automatic watering system maintained a relatively stable moisture content ranging from 41% to 44% throughout the 14-day observation period. This stability demonstrates that the Arduino and IoT-based irrigation system could regulate water supply based on real-time soil moisture data. [18], [19]. The sensor feedback effectively triggered water flow only when the moisture dropped below the threshold (approximately 30%), preventing both overwatering and water stress [20].

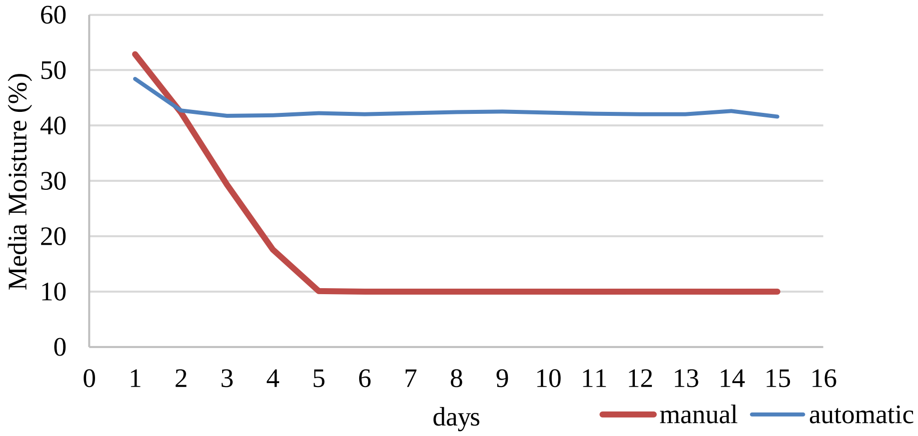

Figure 4. Media moisture percentage over 14 days under manual and automatic watering systems

3.3 Water Usage Efficiency

The total daily water consumption for both systems is presented in Figure 5. The manual watering method showed high and inconsistent water usage, fluctuating between 300 and 500 ml per day. This irregular pattern reflects human-dependent variability and lack of precision in determining the actual irrigation requirement. On some days, excessive watering occurred, while on others, the water provided was insufficient, leading to the observed drop in moisture content [21], [22].

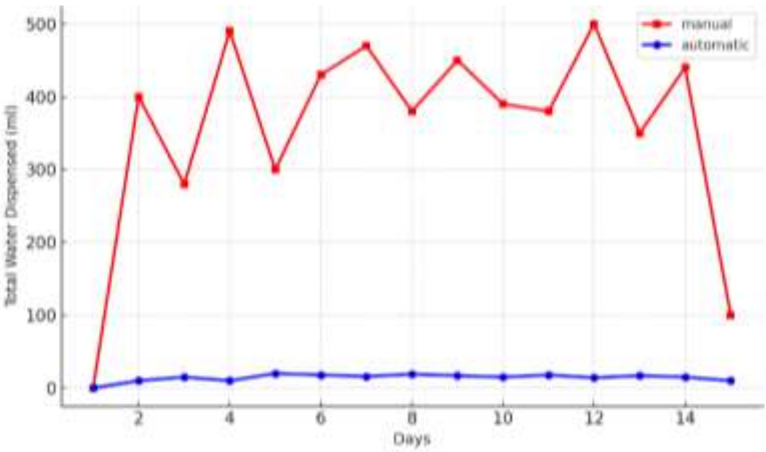

Figure 5. Total daily water consumption for manual and automatic watering systems

Conversely, the automatic system demonstrated minimal and consistent water usage, maintaining a steady pattern of approximately 0–10 ml per day. The system activated the pump only when the moisture level fell below the pre-set threshold, ensuring efficient water utilization. The overall reduction in water consumption highlights the ability of the IoT-based irrigation system to minimize wastage while maintaining optimal soil moisture for Phalaenopsis amabilis growth[23], [24].

3.2 Overall System Performance

The results confirm that the integration of IoT and Arduino technology in the SMASHTHETIC greenhouse provides superior control over irrigation. By automating the watering process based on sensor data, the system ensures environmental stability—particularly in terms of soil moisture—critical for orchid cultivation. The consistent moisture level achieved also suggests potential improvements in plant health, reduced operational labor, and sustainable resource management.

These findings demonstrate that the automatic watering system is more effective and efficient than the manual method, both in maintaining optimal growing conditions and in conserving water resources. The use of IoT platforms also enables remote monitoring and control, offering convenience and improved accuracy in greenhouse management.

4. Conclusion

This study successfully designed and implemented an Arduino and Internet of Things (IoT)-based automatic watering system for the SMASHTHETIC greenhouse to support the cultivation of Phalaenopsis amabilis. The developed system effectively maintained stable soil moisture levels in the range of 41–44%, while the manual watering method resulted in a rapid decrease to around 10% after the fifth day. The automatic irrigation system utilized real-time feedback from soil moisture sensors to regulate water supply, ensuring that irrigation occurred only when necessary.

The results demonstrate that the IoT-based watering system significantly improves irrigation efficiency and consistency compared to manual methods. By maintaining optimal soil moisture conditions, the system supports healthier orchid growth, reduces the risk of under- or overwatering, and minimizes labor requirements for greenhouse maintenance.

Overall, the integration of IoT and Arduino technology has proven to be an effective solution for modern greenhouse automation. This innovation enhances operational efficiency, promotes sustainable water management, and can serve as a foundation for the future development of smart agricultural systems that integrate multiple environmental controls.

5. Acknowledgment

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