Development of an IoT-Based Plant Watering System for Automated Irrigation

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Abstract

The growing demand for sustainable water management in agriculture highlights the need for more efficient irrigation systems. Traditional irrigation methods often lead to water wastage and inconsistent plant health due to issues of overwatering or underwatering. To address these challenges, this study presents the development of an Internet of Things (IoT)-based plant watering system (IoT-PWS) to automate and optimize the irrigation processes in various environments, including homes, offices, and gardens. The IoT-PWS integrates an ESP8266 microcontroller with sensors that monitor key environmental parameters, such as soil moisture, air temperature, humidity, and water levels. The system processes real-time data through the Blynk application, enabling remote monitoring and control. The use of time-series analysis allows for dynamic adjustments to irrigation schedules, ensuring optimal soil moisture and preventing rapid moisture declines. Testing demonstrated that the system maintained optimal moisture levels for approximately 73% of the time, confirming its effectiveness in diverse settings. While the system proved cost-efficient and adaptable, there remains potential for further improvements in sensor accuracy and water usage optimisation. This research contributes to the field of smart agriculture by offering a scalable solution for sustainable irrigation, which could play an important role in reducing water consumption and promoting healthier plant growth. Future enhancements may focus on improving sensor accuracy and further optimizing water usage strategies. This research would contribute to the broader field of sustainable agricultural practices by offering a scalable solution for automated irrigation management, promoting sustainable water usage and healthy plant growth.

Keywords: Automated Irrigation, IoT-Based Irrigation. Smart Plant Watering System, Sustainable Agriculture, Real-Time Monitoring

1.0 Introduction

Maintaining optimal soil moisture is important for healthy plant growth; however, many individuals struggle to achieve this balance due to busy lifestyles, resulting in plant dehydration or overwatering [1], [2]. Automated irrigation systems have emerged as a promising solution, addressing these challenges while ensuring both plant health and water conservation [3]. These systems leverage modern technologies to provide precise irrigation, making them increasingly relevant in agricultural practices and home gardening. However, challenges such as cost, ease of use, and limited monitoring capabilities hinder widespread adoption.

Previous research proposed a smart irrigation system utilising the ESP8266 microcontroller integrated with the Blynk app [4]. The system used soil moisture sensors to monitor water levels and automatically activate the pump when the soil becomes dry [5]. The Blynk app enables users to monitor their plants remotely and receive notifications when soil moisture or reservoir levels are low [6]. The system is designed to be economical and user-friendly, customisable for different plant types in both indoor and outdoor environments, making it easy to implement in homes or offices [7]. Effective irrigation is vital for plant survival and agricultural success but creating an optimal irrigation plan can be challenging and costly, especially when plant mortality is at risk [8]. Many existing irrigation technologies also struggle to effectively transmit critical plant health data to farmers [9].

The lack of an effective, affordable, and user-friendly irrigation system remains a significant barrier. Existing practices often require constant monitoring and manual intervention, which are not feasible for individuals with busy schedules. While some automated systems provide relief, many are either prohibitively expensive or fail to offer real-time monitoring features [8]. Additionally, current technologies often lack effective data transmission regarding soil conditions, leading to suboptimal irrigation results and compromised plant health [9]. This highlights the need for a system that combines affordability, automation, and real-time monitoring to simplify irrigation processes [4].

To address this issue, this study develops a smart irrigation system using the ESP8266 microcontroller integrated with the Blynk app. The system monitors soil moisture, temperature, and humidity levels using sensors, automatically controlling water discharge via a pump. It also provides real-time updates and notifications to users through the Blynk app and automated emails, ensuring optimal irrigation with minimal human intervention. The proposed system's design emphasizes cost efficiency, making it accessible for a broad range of applications, including home gardens, offices, and small-scale farms [7].

The system introduces novel features that enhance its functionality and user experience. By integrating IoT technology with the ESP8266 microcontroller, the design ensures precise irrigation control and real-time monitoring capabilities. Time-series analysis is employed to optimize water usage, while the Adafruit platform allows users to receive immediate feedback on plant and reservoir status, improving system responsiveness [9], [10]. Compared to traditional solutions, this system stands out for its low cost, ease of implementation, and adaptability for diverse environments. These innovations address critical limitations of existing systems, offering an effective solution for sustainable irrigation practices [11], [12]. Table 1 summarizes the IoT-based smart irrigation systems.

This research contributes to the field of smart irrigation by bridging the gap between technology and user accessibility. It offers a cost-effective and user-friendly solution that enhances water conservation and reduces the workload for users, particularly in settings with limited resources or time constraints. The integration of IoT, real-time notifications, and precise control mechanisms demonstrates the potential of the ESP8266 microcontroller for efficient and sustainable irrigation. By improving plant health and minimizing human intervention, this study advances the development of IoT-based agricultural technologies and provides a model for future innovations in the field [13], [14], [15].

Table 1: Summary of IoT-based smart irrigation systems

Authors	Year	Approach	Key Technologies	Results
Ningrum et al. [2]	2023	IoT watering system	Fuzzy logic, Arduino	Optimised automatic watering
Krishnan & Kadir [1]	2019	Precision farming	Smart sensors	98% accuracy, 40% less fertilizer use
Syahri et al. [14]	2022	Greenhouse monitoring	Arduino, Raspberry Pi	Optimised plant growth with remote monitoring
Abd Halim et al. [4]	2023	Smart irrigation for chilli plants	NodeMCU, Blynk, Thinger.io	Improved plant growth, optimised water usage
Reghukumara & Vijayakumar [9]	2021	Smart watering with cloud analysis	Adafruit platform, sensors	Real-time health prediction, water conservation

2.0 Methodology

The IoT-based plant watering system (IoT-PWS) is designed to automate irrigation using real-time data from various sensors. The system relies on the ESP8266 microcontroller to monitor soil moisture, temperature, and water levels. These sensors provide essential data, which is processed by the ESP8266 to activate the water pump when needed. This ensures efficient water usage and optimal plant health. Users can monitor and control the system remotely through the Blynk app, receiving notifications on important conditions like low soil moisture or water tank levels [6].

Key sensor parameters—such as air temperature (25-34.5°C), soil moisture (10-70%), and water level (14 cm)—are continuously tracked to maintain ideal plant conditions. The integration of the ESP8266, which is Wi-Fi enabled, ensures that data is transmitted to the Blynk app in real-time, giving users full control over the system from their smartphones [4]. The system follows a well-structured process, as shown in the software flowchart. This process begins with sensor data collection, followed by analysis to determine whether irrigation is required. For instance, if soil moisture drops below 40% or if air temperature exceeds 40°C, the water pump is triggered to ensure the plants receive adequate hydration [16]. The hardware setup further supports this by efficiently managing the sensors and pump operations, ensuring seamless control of the system. Figure 1 shows the graphical illustration of the IoT-PWS system. This figure shows the ESP8266 controls irrigation by interacting with sensors for soil moisture, temperature, and water levels.

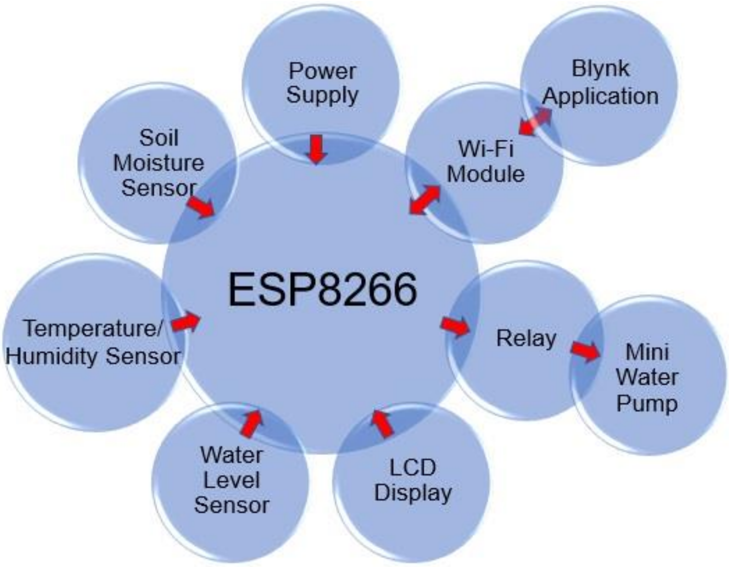

Figure 1: Graphical illustration of the IoT-PWS

Figure 2 shows the ESP8266 microcontroller. This microcontroller serves as the central processing unit of the system. It handles data from sensors and connecting to Wi-Fi for remote monitoring and control.

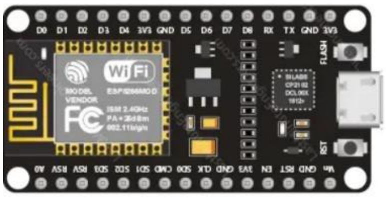

Figure 2: ESP8266

Figure 3 illustrates the Blynk application interface, showcasing real-time data on soil moisture, temperature, and water levels, allowing users to control the irrigation system remotely from their smartphones.

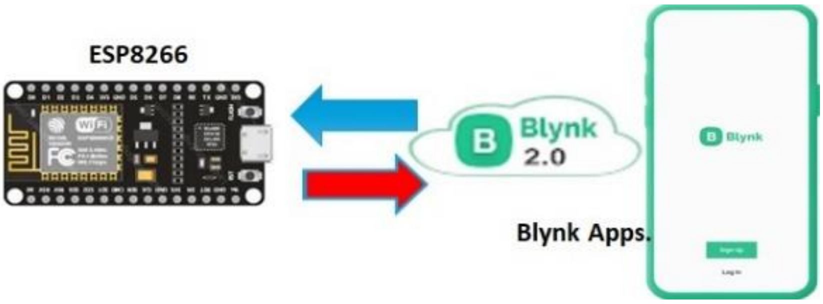

Figure 3: Blynk application

Figure 4 illustrates the system flowchart for both the software and hardware operations of the IoT-PWS. The process begins with the user connecting their smartphone to Wi-Fi and accessing the Blynk application. The ESP8266 microcontroller collects data from the soil moisture, temperature, and water level sensors and sends this information to the Blynk app for real-time monitoring. The system analyses the data, automatically activating the water pump if soil moisture drops below 40% or if the temperature exceeds 40°C. Through the Blynk app, users can monitor and control the system remotely, ensuring efficient plant care.

On the hardware side, the ESP8266 powers up the system and initialises the sensors. If initialisation is successful, it processes the data and transmits it via Wi-Fi for real-time monitoring. This flowchart outlines the sequential steps that enable effective irrigation management through real-time data processing and system control.

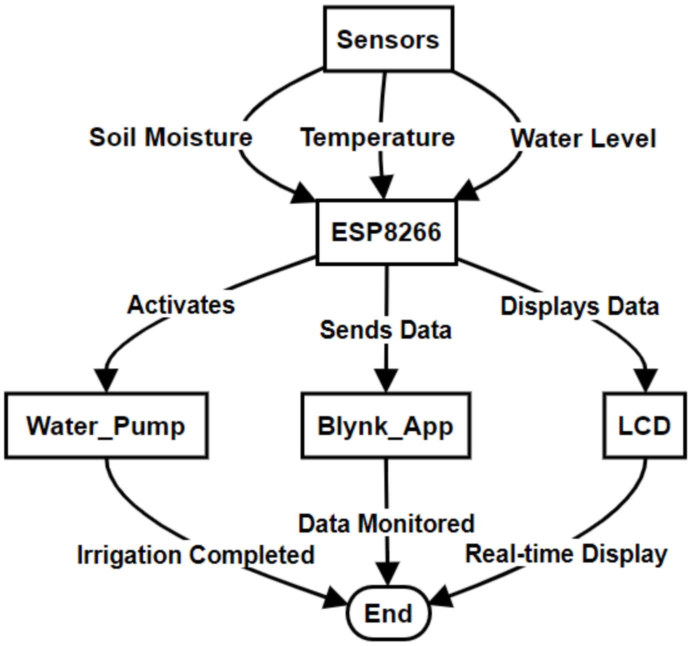

Figure 4: System flowchart for the IoT-PWS

Figure 5 illustrates the circuit diagram showing the connection between the ESP8266, sensors, and water pump, ensuring accurate measurement and control of the irrigation process.

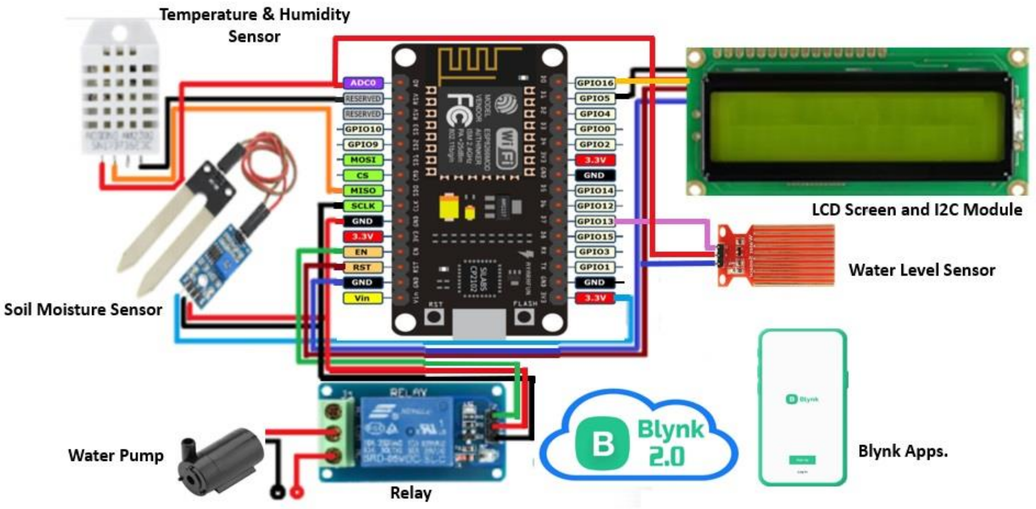

Figure 5: The circuit diagram

2.1 Data Analysis Approach: Methodology for Time-Series Analysis

Time-series analysis is crucial in monitoring environmental variables such as air temperature, soil moisture, and water levels in the IoT-PWS. Hourly data collection from 08:00 AM to 10:00 PM, visualized through line graphs, highlighted key trends, including temperature peaks and moisture declines [17]. The analysis revealed clear daily patterns: temperature rose until midday before declining, with soil moisture following a similar trend. Soil moisture remained stable until noon, then dropped sharply and recovered post-irrigation, demonstrating effective system performance and anomaly detection [18]. Moving averages and smoothing techniques were applied to reduce data noise and improve trend visibility [18][19]. System performance was assessed using a unified formula for rate change [20]:

$$Rate\ of\ Decline = \frac{\Delta\ Measurement}{\Delta\ Time} \tag{1}$$

The formula calculated moisture decline, increase after activation, and water level decrease [20], validating the system's ability to optimize water use and maintain plant health, emphasizing efficient resource management [19].

Time-series analysis is vital for predicting and understanding variable behaviours over time, identifying patterns such as cycles, seasonality, and long-term trends that are not visible from a single data point [21]. In the IoT-PWS, it enables continuous monitoring and adjustment of watering schedules based on real-time data, optimizing water usage and plant health while allowing timely interventions based on past trends [2], [22]. This analysis also detects anomalies by identifying deviations from expected trends, which helps prevent issues like overwatering or drought, maintaining optimal plant conditions [23]. By integrating Time-Series Analysis, the IoT-PWS system becomes more predictive and adaptive to changes, aligning with methods that use real-time data and machine learning for effective maintenance [24].

3.0 Results and Discussion

3.1 System Configuration and Performance

Figure 6 presents the system configuration, performance, and monitoring of the IoT-PWS. The IoT-PWS integrates a soil moisture sensor, water pump, and control unit to maintain optimal moisture levels in the soil. The system is engineered for reliable performance, offering real-time responsiveness to environmental changes [4]. Through the Blynk app, users can monitor and control the system in real-time, with live data on temperature and soil moisture. For example, when the temperature reaches 31°C and the soil moisture falls to 14.66%, the water pump automatically activates at 70% capacity, ensuring the plant's health is maintained [4].

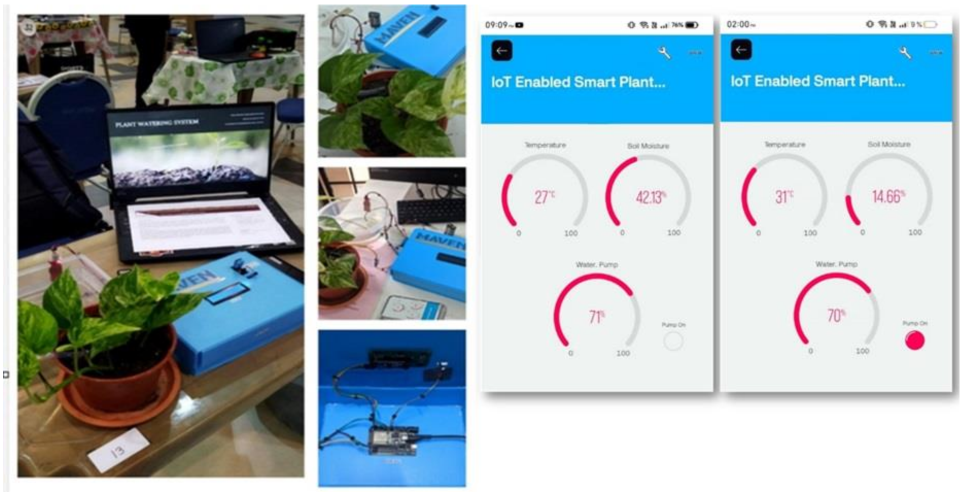

Figure 6: System configuration, performance, and monitoring

3.2 IoT-PWS: Real-Time Data Analysis via Blynk Application

A comprehensive analysis of the IoT-PWS system's performance was conducted by recording data at various intervals throughout the day, from 08:00 AM to 10:00 PM, as shown in Figure 7. This data includes air temperature, soil moisture, water level in the tank, and the status of the water pump. The collected data shows that soil moisture remained stable at around 42% in the morning and evening. However, moisture levels dropped significantly around midday, triggering the activation of the water pump. After activation, the soil moisture gradually returned to optimal levels, reflecting the system's effectiveness in maintaining plant health to quantify this, the optimal soil moisture level of around 42% was maintained for 11 out of the 15 recorded hourly intervals. This equates to approximately 73.33% of the time. The calculation is as follows:

$$Percentage\ of\ Time\ at\ Optimal\ Moisture\ Level = \frac{11\ optimal\ readings}{15\ total\ readings}\ x\ 100\%$$

$$= 73.33\%$$

This calculation demonstrates that the system successfully maintained soil moisture at optimal levels for approximately 73% of the time, indicating its effectiveness in plant health management through the timely activation of the water pump. Air temperature showed an increase from 27.5°C in the early morning to a peak of 31°C at 02:00 PM. The formula for calculating the rate of temperature increase is as follows:

$$Rate\ of\ Increase = \frac{31.0℃ - 27.5℃}{6\ hour} = 0.58\ ℃\ per\ hour$$

After reaching the peak, the temperature dropped to 26.5°C by 06:00 PM, and the rate of temperature decrease is:

$$Rate\ of\ Decrease = \frac{31.0℃ - 26.5℃}{4\ hour} = 1.13\ ℃\ per\ hour$$

There was a slight increase to 29.5°C at 07:00 PM, followed by a final drop to 26.9°C by 10:00 PM. The rate of decline is:

$$Rate\ of\ Decrease = \frac{29.5℃ - 26.9℃}{3\ hour} = 0.87\ ℃\ per\ hour$$

Similarly, the soil moisture change rate is calculated as:

$$Rate\ of\ Decline = \frac{42.03\% - 15.03\%}{1\ hour} = 27\%\ per\ hour$$

$$Rate\ of\ Increase = \frac{42.13\% - 14.27\%}{1\ hour} = 27.86\%\ per\ hour$$

The rate of water level change is calculated as:

$$Rate\ of\ Decline = \frac{75\% - 67\%}{9\ hour} = 0.89\%\ per\ hour$$

$$Rate\ of\ Increase = \frac{70\% - 67\%}{1\ hour} = 3.0\%\ per\ hour$$

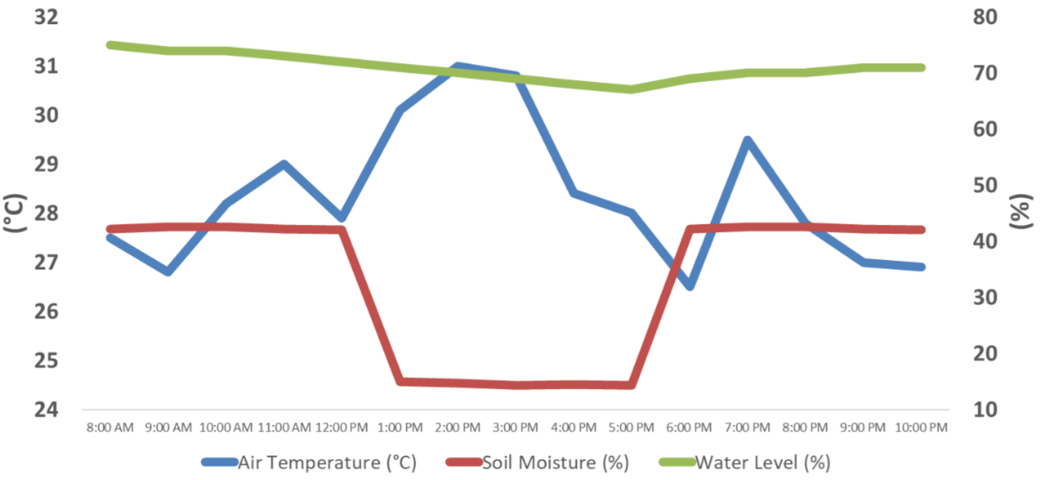

Figure 7: Daily variations of air temperature, soil moisture, and water levels

Building on the time-series analysis of individual parameters, it is crucial to understand the interactions between air temperature, soil moisture, and water levels, as they collectively determine the IoT-PWS system's effectiveness in maintaining optimal soil conditions and conserving water resources. Figure 8 provides a radar chart showing the diurnal dynamics of these three key variables. As the chart indicates, the rise in air temperature (blue) during the morning and its peak in the early afternoon leads to a significant decline in soil moisture (red) due to increased evaporation. The overlapping areas between the temperature and soil moisture lines highlight critical moments for the system to act, activating the water pump to restore moisture levels. This responsiveness is essential to prevent soil desiccation, aligning with findings by Belouafa et al. [19].

Water levels (green) show a gradual decline throughout the day, as the system compensates for moisture loss by dynamically adjusting water delivery based on real-time data. The increase in soil moisture following water pump activation demonstrates the system's effectiveness in managing plant health and minimizing water wastage, as noted by Hashemi-Pour et al. [18]. The combined patterns of air temperature, soil moisture, and water levels illustrate the importance of time-series analysis in capturing daily fluctuations and enabling the system to adapt efficiently to environmental changes. Further exploration by Petropoulos et al. [22] and Elkateb et al. [24] shows how IoT technologies enhance smart irrigation systems, promoting sustainability in agriculture and optimizing resource management, supporting the need for consistent data collection and automated responses, as highlighted by Belouafa et al. [19] and Hashemi-Pour et al. [18].

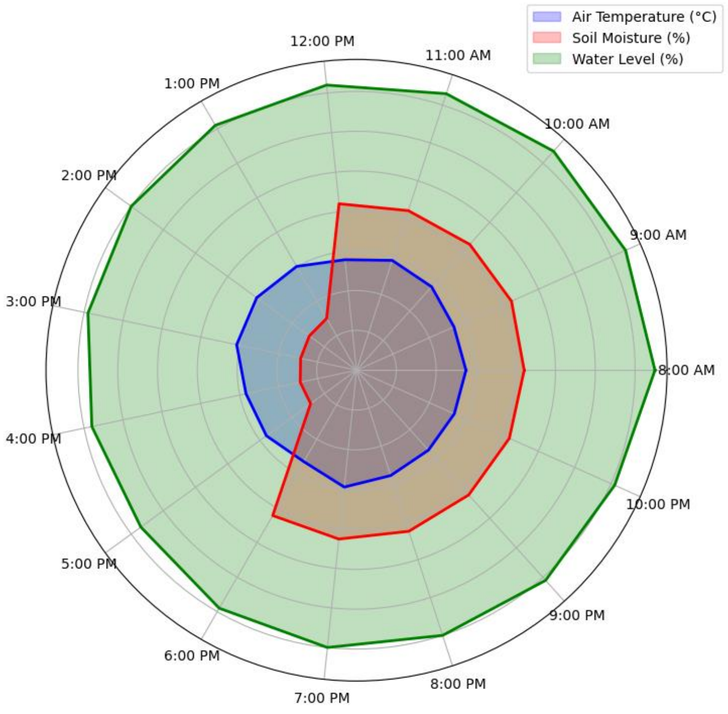

Figure 8: Diurnal dynamics of air temperature, soil moisture, and water levels in IoT-PWS

4.0 Conclusion

Based on the results, it can be concluded that the IoT-PWS developed in this project is both highly effective and cost-efficient, successfully meeting its objectives of real-time monitoring and control via the Blynk application. The system has proven its capability to maintain optimal soil moisture levels by dynamically adjusting water delivery in response to real-time environmental data. During the testing period, the system successfully maintained soil moisture at optimal levels for approximately 73% of the time, demonstrating effectiveness in plant health management through the timely activation of the water pump. The thorough time-series analysis of temperature and moisture levels confirms the system's ability to respond effectively to environmental changes, ensuring efficient water usage and optimal plant health. Although the system performed admirably across various conditions, future enhancements could further improve its performance. These include optimizing water delivery timing to prevent sharp moisture declines, integrating more advanced sensors for increased accuracy, and refining the hardware design to enhance its portability and adaptability for diverse environments.

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Author Contributions

M. Z. A. Rahman: Conceptualisation, Methodology, Software, Writing-Original Draft Preparation, Supervision; **M. H. A. Hamid**: Data Collection, Software and Hardware Implementation, Draft Preparation; **A. A. A. Aziz**: Content-Reviewing, Technical Content.

Conflicts of Interest

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest in the manuscript.

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