FloraHub: An IoT-Based Smart Plant Hydration System with Real-Time Monitoring and Cost Analytics

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ABSTRACT

The "FloraHub: Smart Plant Hydration System" project tackles the shortcomings of traditional plant watering methods by proposing an innovative IoT-based solution. Conventional timed watering systems often result in water wastage and inadequate hydration, adversely affecting plant health and increasing expenses. To address these challenges, the project introduces an automated watering system integrated with soil moisture sensors and water flow sensors. These sensors continuously monitor soil moisture levels in real-time, triggering watering only when necessary, while also providing users the option to utilize a timer or tap a button on the mobile app for manual watering. Additionally, the incorporation of Grafana analytics enables comprehensive data analysis, offering insights into soil moisture trends, watering patterns, and water usage. By leveraging technology and data-driven solutions, the project aims to enhance operational efficiency, minimize water consumption, and promote environmentally responsible practices in plant care. The FloraHub system represents a significant advancement in plant management, providing users with a user-friendly and sustainable approach to ensure optimal plant growth and health.

Keywords- IoT, Smart Irrigation, Sustainable Plant Care, Water Flow Sensor, Automated Watering System

INTRODUCTION

Efficient water management in plant care and agriculture has become increasingly critical due to water scarcity, rising costs, and environmental concerns. Traditional watering methods such as fixed timers or manual watering often led to either overwatering or underwatering, both of which negatively impact plant health and resource efficiency. In particular, auto drip and timer-based systems fail to account for actual soil moisture or environmental changes, resulting in wasted water and suboptimal plant growth.

Recent developments in Internet of Things (IoT), sensor technology, and artificial intelligence (AI) have opened up new opportunities for precision irrigation. Smart irrigation systems that monitor soil moisture, humidity, temperature, and weather forecasts can trigger watering only when needed, thereby improving water use efficiency and reducing labour requirements [1][2]. For instance, IoT-based systems integrating real-time soil moisture sensing with cloud platforms have shown improvements in water conservation and healthy plant growth compared to conventional watering practices [3][4].

There is also growing interest in combining automated irrigation with decision-making algorithms (such as fuzzy logic, PID controllers, or AI prediction models) to further enhance responsiveness and adaptivity of the systems [5]. Moreover, integrating additional data sources such as weather forecasts allows the system to avoid watering when rainfall is imminent, thereby conserving water further [6].

The FloraHub: Smart Plant Hydration System is proposed to address these issues by combining soil moisture sensors, water flow measurement, IoT connectivity, and analytic dashboards to deliver plant watering that is both precise and responsive. The system aims to reduce water wastage, maintain optimum soil moisture, improve plant health, and provide the user with control and insights.

BACKGROUND

The growing importance of sustainable agriculture and water conservation has driven the adoption of automated irrigation solutions. Traditional irrigation techniques, while simple, often lead to inefficiencies such as overwatering, underwatering, and inconsistent soil moisture levels. These issues highlight the need for smarter systems that respond dynamically to environmental conditions rather than relying solely on fixed schedules.

Recent research emphasizes that IoT-enabled irrigation systems provide significant improvements in precision and sustainability by leveraging real-time data from soil moisture sensors and weather conditions [7]. Such systems enable better decision-making, reduce human intervention, and allow scalability from small gardens to commercial farms. Studies also show that integrating smart control with predictive algorithms can improve plant growth outcomes and resource efficiency [8].

Beyond soil sensing, advancements in wireless communication and cloud connectivity have enhanced the reliability and accessibility of smart irrigation. Cloud-linked systems allow users to monitor soil moisture, water usage, and system performance from mobile or web applications, thereby increasing transparency and user control [9]. Furthermore, hybrid systems that integrate automated watering with user-defined schedules provide flexibility for diverse agricultural contexts, balancing autonomy with customization [10].

Energy efficiency has also become a focal point in smart irrigation research. Systems powered by renewable sources such as solar panels demonstrate sustainability and cost savings, making them attractive for rural communities and regions where grid electricity is limited [11]. Meanwhile, combining wireless sensor networks with IoT platforms supports large-scale deployment, enabling distributed monitoring and coordinated irrigation across multiple zones [12].

Despite these advancements, challenges remain in delivering systems that are both cost-effective and user-friendly, particularly for smallholder farmers and home users. Many prototypes lack advanced features such as water flow monitoring, usage analytics, and integration with decision-support dashboards. The FloraHub: Smart Plant Hydration System is designed to address these gaps by combining soil moisture sensing, water flow analysis, IoT automation, and mobile app integration into a single solution. This approach ensures that plants receive adequate hydration while enabling users to track water consumption, optimize costs, and promote sustainable practices.

RELATED WORK

Recent research in smart irrigation has advanced from simple moisture-based systems to more integrated IoT and AI-enabled solutions. Abdelmoneim et al. [13] compared two approaches for precision irrigation, weather-based scheduling using evapotranspiration estimates and soil water potential monitoring with low-cost IoT tensiometers. Their results demonstrated that both methods achieved comparable water productivity, but the sensor-based approach provided more responsive and adaptable irrigation control.

Similarly, Soussi et al. [14] reviewed recent developments in precision agriculture sensors and highlighted the importance of smart data processing for effective irrigation. They emphasized that sensor accuracy, integration with IoT platforms, and real-time analytics are crucial for reliable system performance.

A different perspective was offered by the study on low-power IoT electronics in irrigation [15], which proposed a prototype that combined soil and climate sensors with energy-efficient microcontrollers. This design focused on minimizing energy consumption while maintaining effective irrigation scheduling, making it suitable for long-term deployment in resource-constrained environments.

Dong et al. [16] presented a fully deployed in-field IoT irrigation management system that integrated soil and environmental monitoring with real-time actuation. Their results showed improved efficiency in water distribution and highlighted the practical challenges of large-scale deployment, such as sensor calibration and data handling.

From a socio-technical perspective, Jabbari et al. [17] investigated adoption factors of IoT irrigation in Saudi Arabia using a GRA/AHP decision analysis framework. They found that cost, ease of use, and reliability were the most influential factors for farmer adoption, stressing the importance of usability in system design.

Finally, Kaur et al. [18] developed a hybrid IoT and machine learning irrigation system in Rajasthan, India. By combining multiple sensor inputs with predictive algorithms, the system provided more accurate irrigation scheduling and demonstrated improvements in water savings and crop performance compared to conventional methods.

Despite these advances, many systems either focus on automation without comprehensive user interfaces or prioritize technical efficiency without addressing end-user decision support. In contrast, FloraHub integrates soil moisture and water flow monitoring with IoT automation, mobile app control, and Grafana dashboards to provide not only irrigation efficiency but also cost tracking and actionable insights for users.

TABLE I. Comparison Between Existed and Florahub

Ref	Method / Tools	Key Findings	Identified Gaps
[13]	IoT tensiometers vs. weather-based ET irrigation	Achieved similar water productivity with flexible control using low-cost sensors	Limited to lettuce trials; no analytics or cost tracking
[14]	Review of precision agriculture sensors and smart data	Emphasized importance of sensor accuracy and real-time data processing	Lacked implementation; no end-user application
[15]	Energy-efficient microcontrollers with soil and climate sensors	Reduced power consumption while maintaining irrigation effectiveness	Prototype-level; no dashboard or water usage reporting
[16]	In-field IoT irrigation management with soil/environment sensors and actuation	Improved field water distribution efficiency	Faced sensor calibration issues; lacked cost and usage analysis
[17]	GRA/AHP analysis of IoT adoption factors	Identified cost, reliability, and ease of use as critical for adoption	Focused on adoption; no technical system design provided
[18]	IoT sensors integrated with machine learning for irrigation scheduling	Improved predictive scheduling, water savings, and crop yield	Region-specific trial; no comprehensive reporting tools
FloraHub	Soil moisture + water flow sensors, IoT automation, Flutter mobile app, Grafana dashboards	Provides automation, scheduling, real-time usage tracking, and cost analysis	Bridges gaps by combining technical efficiency with usability and decision-support features

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METHODOLOGY

The project followed an Agile methodology with the Scrum framework, ensuring iterative development and continuous refinement. The workflow included:

Planning

The planning phase served as the foundation for developing the smart irrigation system. At this stage, the problem statement was refined, emphasizing the need to reduce manual watering tasks while ensuring efficient water use for plant growth. The objectives established were: (i) to automate irrigation based on soil moisture levels, (ii) to monitor and record water consumption for cost tracking, and (iii) to provide users with remote control and scheduling features through a mobile application.

To achieve these objectives, a review of existing smart irrigation solutions was conducted to identify common limitations such as lack of cost monitoring, limited scalability, and absence of comprehensive analytics. Hardware and software requirements were then outlined, including the selection of soil moisture and water flow sensors, a Raspberry Pi Pico W as the microcontroller, and a servo motor-controlled valve. On the software side, Flutter was chosen for mobile app development due to its cross-platform capability, while Grafana was selected for data visualization and analysis. This structured planning ensured that resources, scope, and deliverables were aligned with the research objectives.

System Design

At the sensing layer, Figure 1 shows that two main sensors were employed: a soil moisture sensor to detect the hydration level of the soil and a water flow sensor to monitor the volume of water consumed. These sensors provided real-time input data essential for determining whether irrigation should be initiated and for tracking resource usage.

The processing and control layer was implemented using a Raspberry Pi Pico W microcontroller, which served as the central unit for data acquisition and decision-making. The microcontroller was programmed in MicroPython to continuously collect sensor data, process it according to predefined thresholds, and activate or deactivate a servo motor that controlled a 3D-printed water valve. This ensured that water was delivered only when required, minimizing wastage and maintaining plant health.

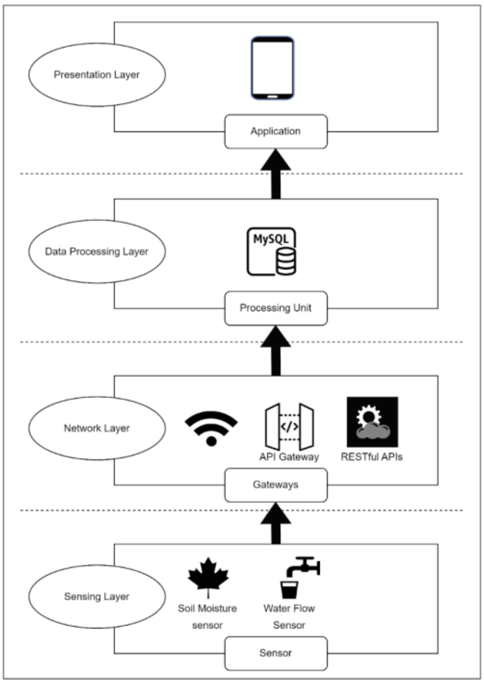

Fig. 1. System Architecture of FloraHub

At the application layer, user interaction and data visualization were facilitated. A mobile application, developed using Flutter, enabled users to select between automatic, manual, and scheduled irrigation modes. The application also displayed real-time soil moisture and water flow readings retrieved from the microcontroller. To enhance decision support, Grafana dashboards were integrated into the system, providing analytical insights into water usage trends and cost over time.

Together, these components formed a modular and scalable architecture capable of supporting both domestic gardening and small-scale agricultural contexts. The design not only automated irrigation but also empowered users with actionable data, bridging the gap between efficiency, monitoring, and usability.

Development

The development stage of FloraHub involved the integration of hardware and software components into a functional prototype. The process began with hardware assembly, where the soil moisture sensor and water flow sensor were configured and calibrated. The soil moisture sensor was adjusted to detect varying hydration levels, enabling accurate identification of dry, moist, and wet conditions. At the same time, the water flow sensor was tested to ensure precision in measuring water volume over time, forming the basis for calculating overall consumption and cost tracking. The Raspberry Pi Pico W microcontroller was selected as the central processing unit due to its wireless connectivity and support for MicroPython programming. It was responsible for acquiring sensor data, executing decision-making rules, and controlling the servo motor attached to a 3D-printed valve that regulated water distribution.

The software development complemented the hardware configuration. The firmware written in MicroPython enabled the microcontroller to read sensor values continuously, process them against predefined thresholds, and actuate the valve accordingly. Data captured from the sensors was then transmitted over Wi-Fi to both the mobile application and Grafana dashboards for real-time monitoring and visualization. The mobile application, developed using Flutter, served as the primary user interface. It provided three distinct irrigation modes: automatic, which activated watering when soil moisture dropped below the threshold; manual, which allowed users to directly open or close the valve; and scheduled, which enabled users to set irrigation routines according to preferred times.

In parallel, Grafana was deployed as the analytics platform to visualize water flow data and generate meaningful insights. The dashboards presented users with clear metrics such as total water usage, frequency of irrigation, and estimated costs, thereby transforming raw sensor readings into actionable information. The development phase, therefore, successfully combined hardware functionality, wireless communication, and user-friendly software into a unified system. This integration ensured that FloraHub was not only capable of automating irrigation but also of supporting informed decision-making through data-driven insights.

Evaluation

The evaluation of FloraHub was conducted using black-box testing, where the system was examined based on its inputs and outputs without considering the internal program logic. This approach was chosen to validate whether the system met its functional requirements from the end-user perspective. The testing process involved simulating different soil conditions, water flow rates, and user interactions with the mobile application to assess the correctness of system responses.

For the soil moisture sensor, dry, moist, and wet soil samples were tested as inputs. The expected outputs were corresponding changes in the application display and appropriate irrigation responses in automatic mode. The results showed that when the soil reached a dry threshold, the system correctly activated the valve, while for moist or wet conditions, irrigation was not triggered.

The water flow sensor was evaluated by allowing measured volumes of water to pass through. The expected output was accurate reporting of water usage within the application and Grafana dashboard. Testing confirmed that the sensor readings were consistent with the actual water volume, enabling reliable tracking of both consumption and cost.

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For the mobile application, black-box testing validated the three irrigation modes. In automatic mode, the system-initiated watering when the soil was dry and stopped when the threshold was met. In manual mode, user input directly controlled the valve, while in scheduled mode, the system activated irrigation at predefined times. In each case, the observed behaviour matched the expected outcomes, demonstrating that the control logic was correctly implemented.

Finally, usability aspects were tested by interacting with the system as a typical user would, verifying that the dashboards displayed real-time data clearly and that system feedback was prompt. Overall, the black-box testing confirmed that FloraHub met its functional requirements effectively, though it also highlighted potential areas for improvement, such as extending wireless connectivity and refining sensor calibration for broader soil types.

TABLE II. BLACK-BOX TESTING RESULTS FOR FLORAHUB

Test Case	Input Condition	Expected Output	Actual Output	Result
TC-01	Soil is dry (< threshold)	Valve opens automatically; irrigation starts; app shows "watering"	Valve opened, irrigation started; app updated correctly	Pass
TC-02	Soil is moist (within threshold)	Valve remains closed; app shows "no watering"	Valve stayed closed; app updated correctly	Pass
TC-03	Soil is wet (> threshold)	Valve remains closed; app shows "no watering"	Valve stayed closed; app updated correctly	Pass
TC-04	500 ml water passed through flow sensor	App and Grafana dashboard show ~500 ml usage, cost updated	Readings showed ~500 ml usage with correct cost	Pass
TC-05	Manual mode: User taps "Start"	Valve opens, water flows, app shows "watering"	Valve opened, water flowed, app updated correctly	Pass
TC-06	Manual mode: User taps "Stop"	Valve closes, water stops, app shows "stopped"	Valve closed, water stopped, app updated correctly	Pass
TC-07	Scheduled mode: Set irrigation at 10:00 AM	Irrigation starts at 10:00 AM automatically	Irrigation started on schedule	Pass
TC-08	Wi-Fi disconnected	App fails to update real-time data; Grafana does not refresh	App showed error; Grafana stopped updating	Pass (error handling verified)

RESULT

The results of the FloraHub development are demonstrated through functional outputs, system responses, and user interactions, as shown in figures below. These figures validate the functionality of the mobile application, automated irrigation system, and monitoring dashboards.

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User Authentication and Profile Management

Figures below displays the results of user account management testing. Password validation and login processes showed appropriate success and error messages. Additional features such as password recovery and registration success were verified, ensuring users could securely access the system (Figure 2). Profile management functions allowed users to update their details, with confirmation messages generated after changes, confirming that account-related modules operated correctly (Figure 3).

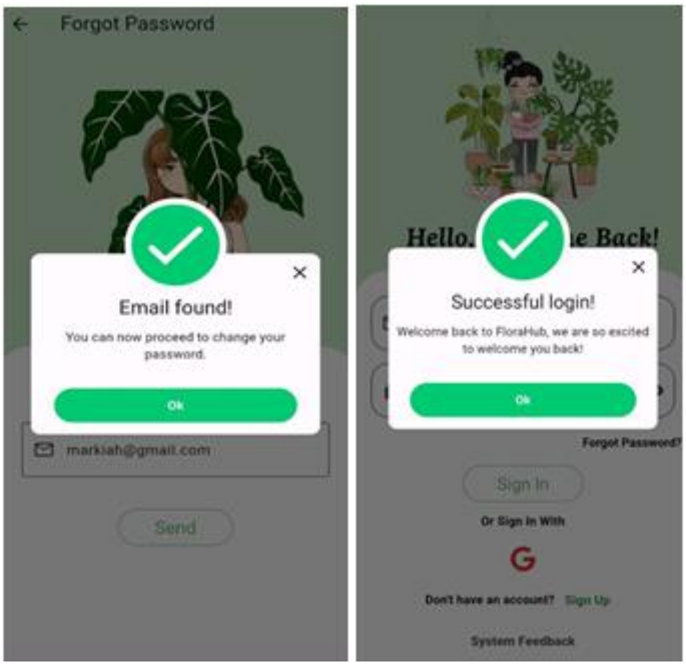

Fig. 2. Login and password verification

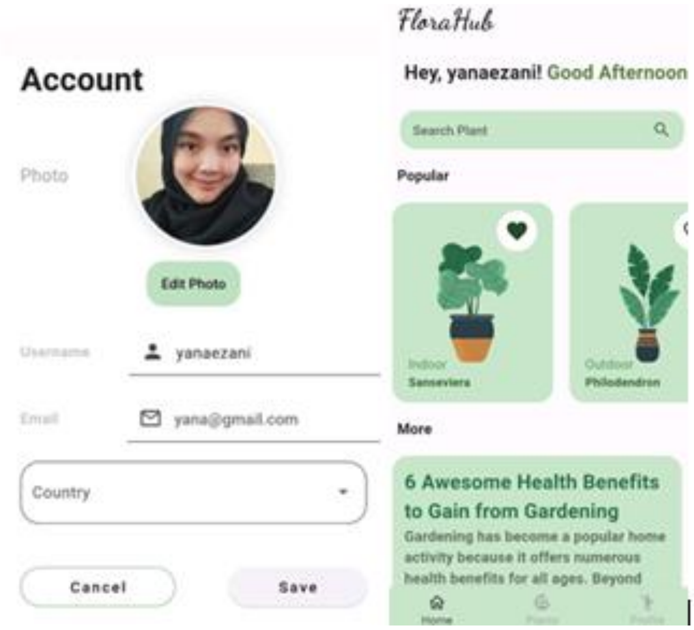

Fig3. Profile management and home page

Soil Moisture Alerts and Manual Watering

Figures 4 illustrate system responses to soil conditions and manual irrigation control. When dry soil was detected, the system alerted users through the application. Manual watering tests confirmed correct execution, with success messages displayed upon activation and deactivation. This demonstrates the reliability of both sensor feedback and user-triggered irrigation.

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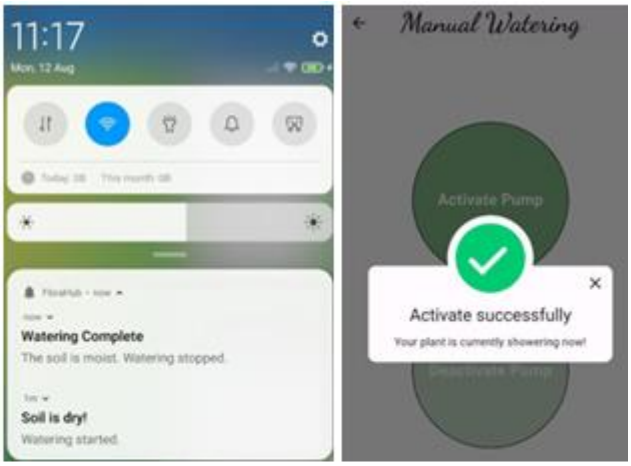

Fig. 3. Alert and manual watering

Scheduled Irrigation

Figures below show the scheduled irrigation functionality. Users were able to add new watering schedules through the scheduling page, with confirmation messages upon successful entry (Figure 5). The system executed watering tasks as planned, as illustrated in Figure 6, proving that automation responded accurately to predefined inputs.

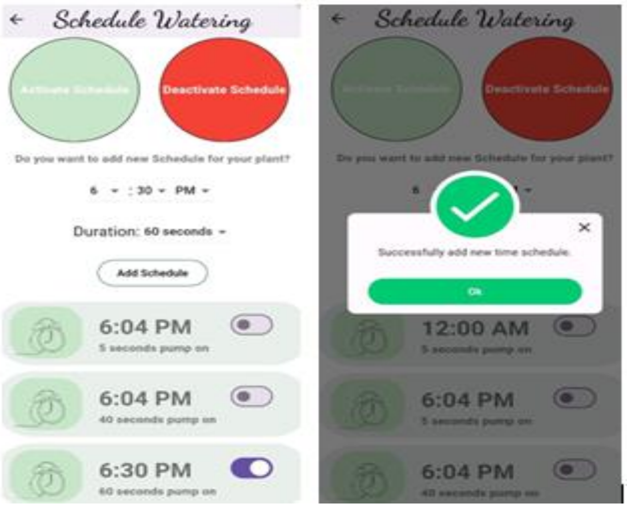

Fig. 4. Schedule of plant watering

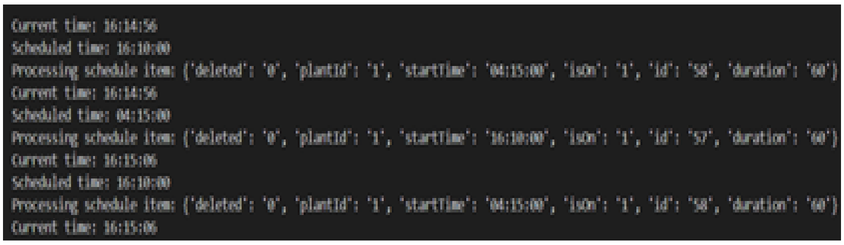

Fig. 5. Execution of scheduled task

Analytics and Monitoring via Grafana Dashboard

Figures below display the Grafana dashboards that provide real-time and historical analysis. Soil moisture trends (Figure 7) and water pattern monitoring (Figure 8) were clearly visualized, supporting informed decision-making.

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Fig. 6. Soil moisture trends dashboard

Fig. 7. Water pattern trends dashboard

Water Cost and Usage Reports

Figures below present the reporting functions of the system. Figure 9 shows the water cost report page, where consumption is translated into monetary value, allowing users to assess irrigation expenses. Figure 10 extends this functionality by offering water usage reports on a daily, monthly, and yearly basis, giving users the ability to monitor long-term patterns. Together, these two reporting features provide comprehensive insights into both cost efficiency and resource utilization, complementing the system's automation capabilities.

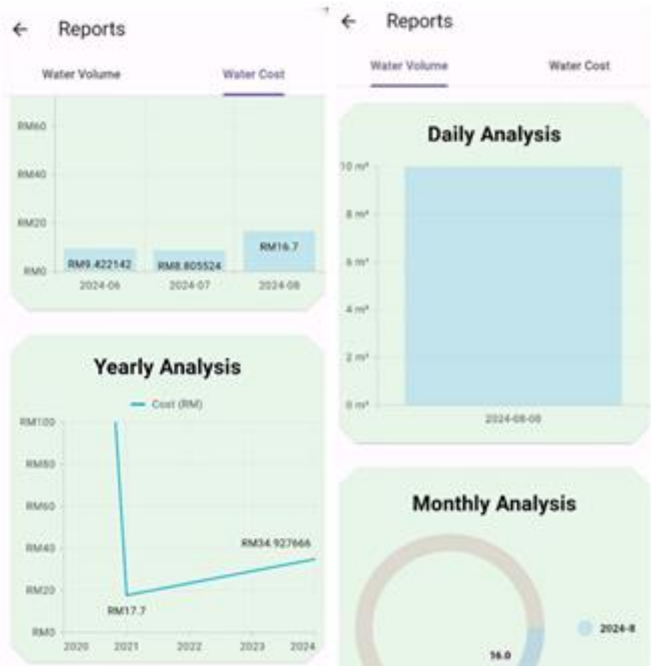

Fig. 8. Water volume and cost reports

CONCLUSION

This study developed and evaluated FloraHub: A Smart Plant Hydration System, which integrates IoT sensors, automated control, and data analytics to optimize irrigation practices. The system combined soil moisture and water flow sensors with a Raspberry Pi Pico W microcontroller and a servo-controlled valve to regulate water delivery. A Flutter-based mobile application provided three irrigation modes: automatic, manual, and scheduled. While Grafana dashboards offered real-time reporting of water usage and cost. The prototype demonstrated that automation and analytics can be effectively combined to reduce manual intervention and enhance decision-making in plant care.

The results confirmed that FloraHub successfully achieved its objectives. Black-box testing validated the reliability of the system across different soil conditions, while functional tests showed accurate monitoring of water flow and consumption. The mobile application proved user-friendly and responsive, and the Grafana dashboards presented data in a clear and actionable format. Compared with existing smart irrigation systems, FloraHub provides a more holistic solution by integrating automation, monitoring, and cost analysis into a single platform, thereby addressing both technical efficiency and user usability.

While the system performed effectively, there remain opportunities for improvement in future work. Extending the Wi-Fi connectivity range would enhance deployment in larger-scale agricultural settings. Integrating predictive algorithms or machine learning could allow the system to anticipate irrigation needs based on weather and soil patterns, thereby improving water efficiency. Additionally, cloud integration could enable remote monitoring and long-term data storage, while renewable energy options such as solar panels could increase sustainability. These enhancements would make FloraHub not only suitable for domestic and small-scale applications but also adaptable to commercial agriculture, contributing further to sustainable resource management.

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