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DEVELOPMENT OF CLOUD-BASED SMART PLANT WATERING SYSTEM

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Abstract: This research investigated the development and evaluation of a cloud-based smart plant watering system designed to automate plant irrigation based on real-time environmental conditions. The purpose of this study was to address the inefficiencies and inconsistencies associated with manual plant watering by integrating environmental sensing technologies, cloud computing, and user-friendly applications. The methodology followed a developmental research approach, incorporating stages such as conceptualization, system design, prototyping, testing, and evaluation. Data was collected using environmental sensors, with the system architecture based on a Raspberry Pi Model 3B controller and cloud services for data storage and monitoring. The evaluation process included 32 evaluators (13 in-person and 19 online), who assessed the system's hardware (interface circuits) and software (desktop and mobile applications). Evaluation instruments comprised a five-point Likert scale and ISO/IEC 25010 standards, with statistical analysis performed using SPSS version 27.

The system demonstrated effective automation of irrigation using a modular setup of environmental sensors, a microcontroller, and cloud-based monitoring accessible via desktop and mobile platforms. Performance testing revealed the system's rapid and responsive moisture regulation, with Sensor 3 recording a moisture increase of 78.33% in 29 seconds (162.07%/s), confirming high efficiency in water delivery. Despite some sensor anomalies and environmental variability, consistent trends in data validated the system's reliability. User evaluation of the external interface circuit yielded an average satisfaction score of 4.77, while application usability under ISO/IEC 20510 standards averaged 4.59, both categorized as "Very Acceptable." Limitations included the absence of backup power and local monitoring options, though future enhancements involving AI and blockchain were identified to improve precision and data security.

Keywords: Cloud-Based, Watering, Automation, Sensor data, Development, Evaluation.

I. INTRODUCTION

Growing a plant involves several key steps and considerations to ensure its successful growth. Different plants have different requirements, so it is essential to research and understand the specific needs of the plant you are trying to grow. Gardening can be a rewarding hobby, and learning about the plants you are growing will contribute to your success. There are several outlines of how to grow a plant. Some of which are location, proper sunlight, fertilization, and the major outline to be consider are watering, and the soil.

Plants should be watered according to its specific needs. Some plants like to dry out between waterings, while others prefer consistently moist soil. Be careful not to overwater or underwater (Missouri Botanical Garden, 2025); the frequency will depend on factors like humidity, plant type, and season. Use well-draining soil that is appropriate for the type of plant to be grown. Some plants prefer acidic soil, while others thrive in alkaline soil. Sometimes soil must be amended with compost or other organic matter for proper growth of a plant (Better Home & Garden, 2023).

Manual watering of plants can lead to problems such as overwatering, which can cause root deterioration and waterlogged soil, or underwatering, resulting in wilting and stunted growth (Smith et al., 2020). Inconsistent watering practices might lead to uneven growth and stress on plants. Watering at inappropriate times, like during the hottest part of the day, can result in water loss through evaporation, and improper watering techniques such as watering too quickly or from overhead can lead to soil compaction and leaf diseases (The Spruce. Top garden watering mistakes to avoid 2023). Additionally, water quality issues and neglecting plant-specific water needs can impact overall plant health, while not using mulch can contribute to rapid moisture loss and weed growth.

With various issues regarding manual watering, there are several concerns that needs to be addressed to justify for research study (ITM Lab, 2022). Some concerns to be consider are water supplies became polluted and scarce and necessity to use water resources such as rivers, ground water and rain water efficiently has increased rapidly (Farrelly,

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2023). Also, a study has been made on the clay soil to observe its behavior and its different characteristics affecting plant growth (GardenerBible - How Does Clay Soil Affect Plant Growth, 2024). In some case, watering stations is needed in which each station is irrigated in accordance with the specific soil needs at that station. Efficient use of water is necessary since one of the major global concerns of our current era is water scarcity (WHO, 2022).

There are existing automated plant watering that addresses the issues however this kind of system can be develop with a much better IoT (Internet of Things) device. Existing system also lacks of online or off-line status monitoring. Users of the system has no option to set the amount of water and soil moisture and bound to the programmer settings in the code which implies that it has no database to record the settings (Borah et al., 2021). Some other deficiencies of the existing watering system include multi-platform device application is limited if not lacking, IoT device used in the system depends only on a cloud for connectivity all the time (Angelopoulos et al., 2021), and hobbyist or enthusiast IoT devices are used (Kumar et al., 2019).

With the deficiencies of an existing automated watering system, this leads to the following ideas that this study came up which focused on the development of smart plant watering system with an IoT devices, such as Raspberry Pi (Kavita et al., 2022). This device is much more capable for such purpose with monitoring and controlling. This is a computer in a compact size with build-in networking capabilities. It is also much more efficient and can be interactive since applications can be develop with easy access to internet and media capabilities. The system would integrate an online or off-line status monitoring and control of the system which employs web browser, iOS, Android, and desktop applications. It also has a capability for users to define any values to the application's settings. This application can be installed in several independent devices. In such case, the system can also employ industry standard IoT devices other than Raspberry Pi.

II. METHODOLOGY

The study employed the developmental research method, which proved highly suitable for the creation of the cloud-based smart plant watering system. This approach focuses on the design, development, and refinement of innovative technologies or systems, making it ideal for projects aimed at building practical and functional prototypes. In this case, the developmental method supported the systematic development of the smart watering system by guiding the process from problem identification—specifically, the challenge of inefficient and inconsistent plant watering—through the stages of conceptualization, design, development, testing, and evaluation.

Each phase required careful planning and execution, and the developmental research framework provided a clear and organized structure for navigating these stages (Plomp et al., 2018). A key strength of this method is its iterative nature, which emphasizes continuous improvement. Throughout the system's development, it underwent regular testing and evaluation, with feedback from each cycle informing enhancements to its design and functionality.

This iterative refinement was essential in ensuring that the system not only functioned correctly but also met real-world needs in terms of automation, efficiency, and remote control. Ultimately, the use of the developmental research method enabled the creation of a reliable prototype that effectively addressed the limitations of manual plant care. It ensured the system evolved in response to performance evaluations, making it the most appropriate methodology for developing a robust, cloud-based smart plant watering solution.

Design Planning Phase

Figure 1 presented the block diagram illustrating the conceptualization of the developed system. It outlined the necessary activities and information flows within the system. In automatic mode, the moisture sensor first detected the soil's water content before initiating the watering or irrigating process. In time mode, however, the watering or irrigating was carried out based on the predefined time and duration set in the system, regardless of the moisture sensor readings. The system could be monitored, controlled, and configured both locally and remotely, either online or offline, using a desktop or mobile application. Mobile devices utilized internet connectivity to provide a comprehensive user experience. This connection enabled them to perform a variety of functions, including monitoring, controlling, and adjusting settings, mirroring the capabilities of the desktop application. Additionally, the system allowed for the modification of user accounts for those who were currently logged in. A speaker was also connected to the local MCU to serve as an alert mechanism. The alert was triggered when the pump remained continuously active beyond a specified duration, indicating that the moisture level had not changed or increased—an abnormal system behavior. This feature enabled the user to identify and address potential issues, ensuring the system operated efficiently.

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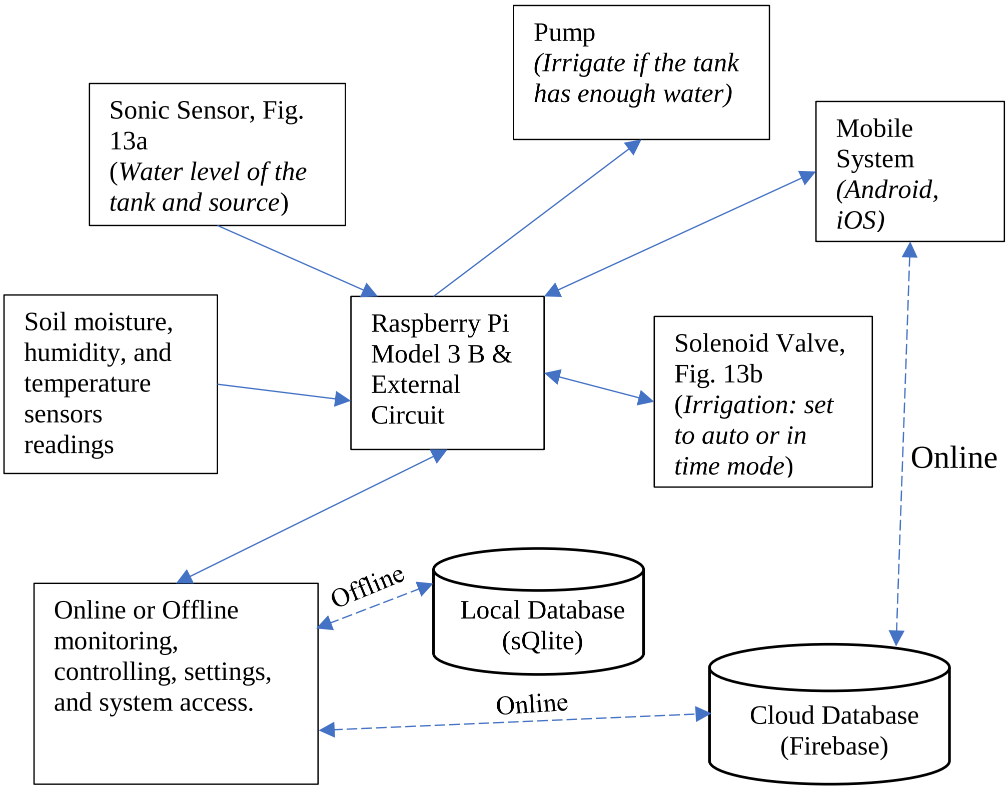
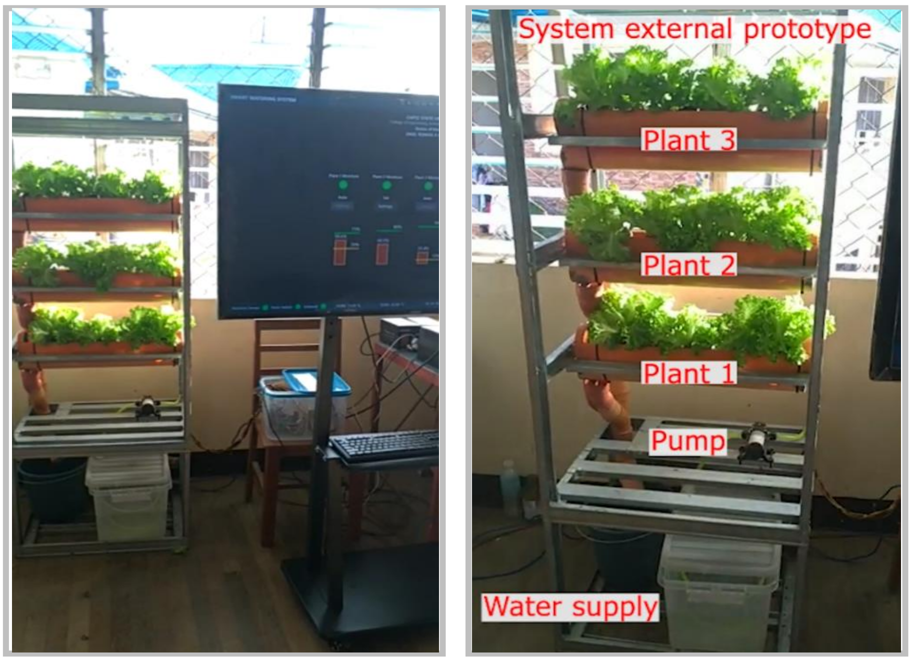


Figure 1. Block Diagram of the System showing the data flow and device interactions

Figure 2 presents the prototype of the system, showcasing its overall design and external structure. Figure 2(a) highlights the complete system setup, while Figure 2(b) focuses on the external prototype, giving a closer look at the physical components and arrangement.



(a) (b)

Figure 2. Prototype (a) System. (b) External Parts

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Figure 3 provides a CAD layout of the circuit, offering a structured representation of its design and placement. This illustration helps visualize how different components are integrated into the system

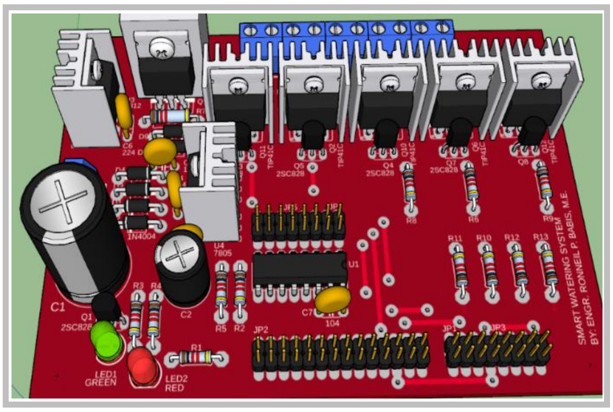

Figure 3. External Circuit CAD layout

Figure 4 presents the actual external interface circuit, highlighting its various connections and emphasizing the primary components related to water distribution. Meanwhile, Figure 5 showcases the Raspberry Pi Model 3B along with its connections to the external interface circuit and other critical peripherals. This figure underscores the role of the Raspberry Pi as the system's central processing unit, illustrating how it manages communication with the connected hardware to ensure efficient system operation.

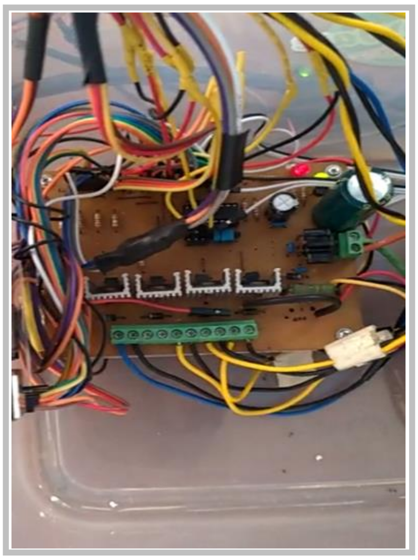

Figure 4. External interface circuit showing various

Figure 5. Raspberry Pi Model 3B showing its connections to external interface circuit and some attached peripherals

Figure 6 showcases the Mobile Android application, which serves as the user interface for monitoring and controlling the system remotely. Figure 6(a) displays the login page, where users are required to enter their credentials to gain secure access to the application. This authentication process ensures that only authorized users can interact with the system, enhancing security and preventing unauthorized modifications.

Upon successful login, the home screen (Figure 6.b) displays key information, including:

- Plants: Cyan rectangles represent soil moisture levels. Green and blue lines indicate the maximum and minimum soil moisture thresholds for irrigation, respectively. Plants 1 and 3 are in automatic irrigation mode, while Plant 2 uses a timer.

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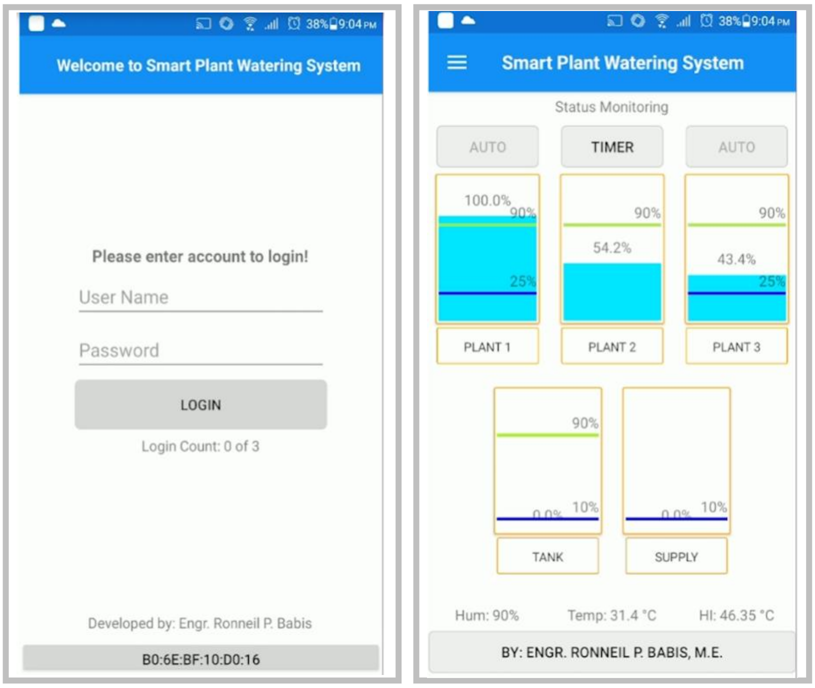
- Tank: A cyan rectangle shows the water level. Green and blue lines represent the maximum and minimum water levels for controlling the water pump.
- Water Supply: A cyan rectangle indicates the water level, and a blue line shows the pump's de-energization threshold.
- Environment: Humidity, temperature, and heat index readings from the sensor are also displayed.

This main interface provides an overview of the system's current status, including real-time data on soil moisture, temperature, and humidity levels. Additionally, it features interactive controls that allow users to manually activate or adjust irrigation settings. The intuitive design of the home page ensures ease of use, allowing users to manage the system efficiently from their mobile devices, even when away from the main desktop interface.



(a) (b)

Figure 6. Mobile Android App (a) Login page. (b) Home page.

Figure 7 shows the desktop application installed on the Raspberry Pi Model 3B. It displays the moisture status of each plant, as well as the water levels in the tank and water supply. Specifically:

- Plants: Orange rectangles represent soil moisture levels. Green and orange lines indicate the maximum and minimum soil moisture thresholds for irrigation, respectively. As shown, plants 1 and 3 are in automatic irrigation mode, while Plant 2 uses a timer.

- Tank: A blue rectangle shows the water level. Green and orange lines represent the maximum and minimum water levels for controlling the water pump.

- Water Supply: A blue rectangle indicates the water level, and an orange line shows the pump's de-energization threshold.
- Environment: Humidity, temperature, and heat index readings are displayed.

The application's main UI also shows the system time and sensor status. Green shaded circles indicate detected sensors, yellow circles indicate one or more undetected sensors within a sensor group (e.g., moisture sensors), and red circles indicate all sensors in the group are not detected. Green shaded circles for plants, tanks, and water supply indicate that soil moisture and water levels are above the minimum threshold. Red circles indicate levels are below the minimum.

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Figure 7. The Desktop Application

III. PRESENTATION, ANALYSES AND INTERPRETATION OF DATA

The analysis of three soil moisture sensors, along with humidity and temperature readings, revealed significant patterns of soil moisture increase during irrigation events. Moisture Sensor 1 recorded a moisture rise from 38.5% to 67% within just 17 seconds, with a rapid moisture change rate of 100.59% per second, although slight negative environmental influences were observed (r = -0.04). The data from Sensor 2 showed an even larger moisture gain, from 9.67% to 54.67% over 52 seconds, with a change rate of 51.92% per second, and a minor negative influence of environmental conditions (r = -0.063). Sensor 3 recorded the most substantial increase, from 7.67% to 86.00% in 29 seconds, with an impressive moisture change rate of 162.07% per second, and a minimal positive environmental correlation (r = 0.047). Graphs of the raw moisture readings consistently showed a downward trend during irrigation, confirming the inverse relationship between raw readings and actual soil moisture levels. Initial fluctuations were noted in all three datasets, likely caused by soil heterogeneity or sensor sensitivity, but clear trends of effective water absorption were observed afterward.

The soil moisture readings from Sensors 1, 2, and 3 revealed notable variations in moisture dynamics during irrigation. For Sensor 1, the hysteresis margin varied widely, from 129.63% indicating strong moisture replenishment to -2.67% suggesting minimal or inconsistent changes, likely affected by sensor calibration or environmental factors. Recovery times and moisture change rates also fluctuated, with high rates like 252% per minute reflecting rapid absorption and negative rates indicating evaporation or poor irrigation efficiency. Similarly, Sensor 2 showed differences in absorption rates, with some events indicating high moisture gains (up to 95.77%) and others showing minimal or even negative changes, hinting at potential soil or drainage issues. Sensor 3 demonstrated a mix of stable and highly irregular readings; some sessions indicated efficient absorption, while extreme anomalies—such as hysteresis margins exceeding 300% and change rates over 2000%—suggested potential sensor errors or sudden environmental changes. Across all sensors, the correlation coefficient ("r") showed that environmental conditions like temperature and humidity had varying impacts, sometimes positively and other times negatively influencing soil moisture behavior.

The evaluation results for the external interface circuit across various categories — Functionality and Purpose, Design Documentation and Replication, Practical Application and Usability, Testing and Reliability, and Overall Satisfaction — consistently showed a "Very Satisfied" rating from both in-person and online evaluators. In the Functionality and Purpose category, the circuit achieved an overall mean of 4.80, affirming that it met its functional and operational objectives effectively. For Design Documentation and Replication, the high mean of 4.77 reflected clear, comprehensive, and easy-to-follow documentation that supported replication efforts. Practical Application and Usability also received strong ratings, with a mean of 4.71, highlighting the circuit's real-world practicality and user-friendliness. In terms of Testing and Reliability, the mean score of 4.76 indicated that the circuit performed consistently under various conditions and that the testing methods were robust and well-documented. Lastly, the Overall Satisfaction dimension recorded the highest scores, reaching an overall mean of 4.82, showing that users felt the product met or exceeded expectations and would

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recommend it to others. Overall, the External Circuit achieved an impressive overall mean of 4.77, confirming consistently high satisfaction across all aspects evaluated.

The evaluation results across all dimensions of the Desktop and Mobile Applications show consistently high levels of user satisfaction. For Functional Suitability, users were very satisfied with the apps' completeness, correctness, and appropriateness. Performance Efficiency scores also reflected quick response times and efficient resource utilization. In Compatibility, the apps were found to coexist well with other systems and effectively share information. Usability scores indicated that users found the apps easy to learn, operate, and access, with positive user experiences across different demographics. Reliability results showed that the apps generally performed well under different conditions, though fault tolerance and recovery had slight areas for improvement. For Security, the apps achieved high ratings in confidentiality, integrity, and non-repudiation, showing strong protection measures. Maintainability and Portability were also rated very highly, with minor suggestions for improving ease of modification and installation processes. Overall, the applications achieved a mean satisfaction score of 4.59, categorized as "Very Satisfied" across all evaluated dimensions.

IV. CONCLUSION

Based on the findings, the cloud-based smart plant watering system provides a basic yet functional solution, but it also reveals critical areas for improvement. Specifically, its lack of a backup power source compromises reliability during outages, particularly in regions with unstable electricity, while the absence of local monitoring outside the desktop application limits usability in remote or large-scale settings. Addressing these gaps would enhance both resilience and user convenience. The potential integration of AI and blockchain technologies presents promising avenues for future development, offering enhanced operational efficiency, real-time adaptability, data accuracy, and secure information handling.

From a performance standpoint, the system has demonstrated high efficiency in rapidly increasing soil moisture levels, regardless of minor environmental fluctuations such as temperature and humidity. The sensors effectively captured moisture dynamics, with recovery times and hysteresis margins confirming successful water absorption. Although initial data inconsistencies and environmental influences were observed, they remained minor and manageable. Notably, the downward trends in moisture readings following irrigation suggest effective water penetration once saturation thresholds are met, while slight negative environmental effects indicate a need for optimized irrigation schedules that account for ambient conditions.

However, the system's performance is not uniform across all sensors. In particular, Sensor 3 displayed inconsistent and extreme readings, underscoring the need for improved calibration and environmental monitoring. Variations in recovery times and irregular hysteresis margins point to potential inconsistencies in sensor behavior and system performance. These issues highlight the importance of incorporating adaptive, feedback-based irrigation strategies to account for soil characteristics and environmental factors, ensuring both water efficiency and plant health.

In terms of hardware and software components, the interface circuit performed exceptionally well, as evidenced by consistently high satisfaction ratings. Its clear documentation, user-friendly design, and reliable operation across various scenarios contributed to its accessibility and effectiveness, even for users with limited technical experience. Similarly, the Desktop and Mobile Applications were found to be highly functional, secure, and compatible across platforms. While minor shortcomings were noted in areas like fault tolerance and modifiability, these did not significantly impact user satisfaction, indicating overall success in supporting user tasks and enhancing the system's operability.

In conclusion, the system offers a solid foundation for smart irrigation, showing strong potential in both functionality and user satisfaction. Nonetheless, targeted improvements—particularly in power resilience, local monitoring, sensor calibration, and adaptive scheduling—are essential for advancing the system from a functional prototype to a more robust, intelligent, and scalable solution.

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