Review Article

Design and Develop Automated Plant Watering Unit Based on Real-Time Soil Moisture Monitoring for Optimal Growth

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Abstract: This project presents a design and development of an automated plant watering unit that assists in maintaining optimal plant hydration through real-time soil moisture monitoring. The system employs soil moisture sensors to continuously assess moisture levels and automatically activates watering when the soil moisture drops below a specified threshold. This will ensure efficient water use, promote healthy plant growth and same time conserve water resources. The unit is designed and developed as a low-cost and user-friendly solution, the unit is suitable for various applications, including home gardens, community green spaces, and agricultural settings. Its adaptability and focus on resource efficiency make it an effective tool for enhancing plant care and supporting sustainable watering practices.

Introduction

Effective water management is essential for promoting healthy plant growth and fostering sustainable gardening and agricultural practices. Traditional watering methods, often based on guesswork, can result in over-watering or under watering, leading to plant stress, reduced yields, and unnecessary water waste. While some automated water supply systems exist, they can be complex, costly, or lacking in simplicity and adaptability for various users and environments. Recognizing these challenges, this project focuses on developing an automated plant watering unit centered on real-time soil moisture monitoring to achieve optimal plant growth.

The system will utilize soil moisture sensors to continuously assess the water content in the soil. When moisture levels fall below a predetermined threshold, the unit automatically activates the watering process, ensuring that plants receive the right amount of water at the right time. This targeted irrigation approach not only conserves water but also enhances plant health by preventing the detrimental effects of inconsistent watering. By focusing on real-time monitoring, the system maintains soil moisture within an ideal range, supporting consistent plant development and maximizing crop yields.

Designed as a low-cost and user-friendly solution, the automated watering unit is adaptable for diverse settings, including home

gardens, urban green spaces, community gardens, and larger agricultural fields. Its scalability ensures that users ranging from hobbyist gardeners to commercial farmers can benefit from improved watering efficiency. Additionally, the system reduces the need for manual intervention, allowing users to save time and effort while promoting sustainable water use.

This study will emphasize the design, development, and testing of the automated plant watering unit, evaluating its effectiveness in maintaining optimal soil moisture levels and enhancing overall plant growth. By providing a practical and accessible solution to common watering challenges, the project aims to contribute to resource-efficient gardening practices and broader sustainability goals in agriculture.

Problem Statement

Inefficient water management remains a pressing challenge in modern agriculture and gardening, with traditional watering methods often relying on subjective judgment. Such approaches frequently lead to over-watering or under-watering, which can compromise plant health, reduce soil fertility, and waste valuable water resources. These inefficiencies not only hinder optimal plant growth but also contribute to environmental degradation and increased labor demands. Although automated watering systems have emerged to address some of these issues, many existing solutions fall short in user-friendliness, cost-effectiveness, and real-time responsiveness, limiting their widespread adoption.

To overcome these challenges, this project focuses on developing an automated plant watering unit centered on real-time soil moisture monitoring to ensure optimal plant growth. By continuously assessing the soil's moisture levels, the system can accurately determine when watering is necessary, eliminating guesswork and reducing water wastage. Unlike conventional systems, this solution prioritizes precision and efficiency, delivering the right amount of water at the

right time to maintain ideal growing conditions. Its design emphasizes ease of use and affordability, making it accessible for various applications, from small-scale home gardens to larger agricultural settings.

Beyond improving water use efficiency, the automated unit supports plant health by preventing common issues associated with improper watering, such as root rot from over-watering or wilting from drought stress. By maintaining consistent soil moisture, the system promotes stronger root development and enhances overall plant resilience. Additionally, the technology can be adapted for different environments and plant types, offering scalability and versatility across diverse growing conditions.

This solution not only contributes to water conservation but also reduces the labor involved in traditional plant care, freeing users from the need for constant manual monitoring and watering.

By fostering sustainable watering practices, the automated plant watering unit plays a vital role in addressing global concerns related to resource management and environmental sustainability. Its implementation will mark a significant step toward more efficient, eco-friendly, and effective plant care solutions in both agricultural and horticultural contexts.

Aim

Design and Develop a low-cost, based automated plant watering system that optimizes irrigation through real-time soil monitoring, thereby conserving water and enhancing plant health.

Objectives

- To Design and develop an integrated hardware system with an Arduino, sensors (moisture, temperature, humidity, water level), and a water pump.

- To Implement automated watering that activates when soil moisture drops below a set threshold.

- To Validate the system's performance and water conservation benefits through comprehensive testing.
- To Create a mobile application for easy remote monitoring and control. (optional)

Scope

The scope of this project will include:

- To design and develop of an automated watering mechanism that initiates irrigation based on real-time soil moisture sensor data.
- Integration of multiple sensors (humidity, soil fertility, temperature, and water level) to continuously monitor environmental conditions and soil health.
- Creation of a user-friendly mobile application for remote monitoring and control of the watering system. (optional)

With the growing global need for sustainable agricultural technologies, an automated plant watering system offers a promising solution. This project will explore the design, operational dynamics, and efficacy of such a system, aiming to provide robust data that supports its practical adoption. By enhancing water conservation, labor efficiency, and plant health, the initiative seeks to advance sustainable practices and optimize resource management across diverse agricultural and gardening contexts.

Literature Review

The increasing pressures of rapid urbanization, climate change, and water scarcity necessitate efficient water management in both agriculture and home gardening. Automated plant watering systems offer a promising solution by delivering precise amounts of water when needed. This literature review focuses on the design of automated plant watering units based on real-time soil moisture monitoring, exploring how these systems can optimize plant growth, conserve water, and reduce manual labor, ultimately supporting sustainable practices.

As Đuzić and Đumić (2017) point out, these systems have become pivotal in modern horticulture by addressing inefficient water management. This review will examine the core components and design principles of such units, including the integration of soil moisture sensors, control mechanisms, and water delivery systems.

Astutiningtyas, Nugraheni, and Suyoto (2021) highlight the benefits even for small-scale gardens, where automation saves time and sustains optimal growth. The use of precise sensor technologies coupled with micro-controllers, such as Arduino, enables responsive water delivery based on current soil conditions (Divani and Patil, 2018). While the focus remains on the core functionality of these units, the potential for integrating internet of things elements (IOT), like remote monitoring via mobile applications (Joaquinetal., 2020), will also be considered, particularly for larger agricultural settings.

Raoetal. (2023) emphasize the significant water conservation advantages of precision irrigation, and recent systematic reviews (2023) underscore the long-term economic benefits, including reduced labor and resource expenses.

Overview of Automated Plant Watering Systems

Automated plant watering systems are advanced technologies designed to monitor soil moisture levels continuously and dispense water as needed. Their primary purpose is to ensure that plants receive an optimal amount of hydration, which is crucial for their health and productivity. By automating the watering process, these systems significantly reduce the risk of human error, preventing both over watering and under watering. This leads to more consistent growing conditions, which are essential for promoting healthy plant growth and maximizing yield.

Types of Automated Plant Watering Systems

Automated plant watering systems have evolved into a diverse array of technologies, each tailored to meet specific gardening and agricultural needs. This section details the various types of systems, examines their unique benefits and suitability for different environments, and explores the possibility of integrating two or more systems for enhanced performance.

Recirculating Irrigation

Recirculating irrigation systems are designed to mimic the natural water cycle. In these systems, a water pump draws water from a storage tank and delivers it to the top of a vertical planter. As water percolates through each pot, it irrigates the plants and is then collected back into the tank for reuse. This closed-loop approach can conserve over 50% of water and nutrients compared to conventional methods. The addition of digital or Wi-Fi timers enables precise scheduling, ensuring that each plant receives just the right amount of water (Citysens, n.d.).

Drip Irrigation

Drip irrigation delivers a controlled, slow flow of water directly to plant roots through a network of tubes equipped with small drippers. This method minimizes evaporation and runoff, making it highly efficient for water use. Drip systems are adaptable to various garden layouts and plant types.

In vertical gardening, pressure-compensated drippers are recommended to guarantee uniform water distribution across all plants. Timer integration further refines the schedule, making this system ideal for both residential gardens and larger agricultural applications (Citysens, n.d.; Irrigationtech, n.d.).

Capillary Irrigation

Capillary irrigation harnesses the natural capillary action of materials such as cotton strings or wicks. In this system, a wick draws water from a reservoir, delivering a steady, low-level moisture supply directly to the soil. This method is particularly beneficial for small-scale gardens or indoor plants that require consistent hydration without the risk of over watering (Citysens, n.d.).

Sprinkler Systems

Sprinkler systems replicate natural rainfall by spraying water over a wide area. They are commonly used for lawns, large gardens, or extensive agricultural fields. These systems consist of interconnected pipes and sprinkler heads, including pop-up models that retract when not in use to prevent damage. Although they provide broad coverage, efficiency may be reduced in arid climates due to wind drift and evaporation (Irrigationtech, n.d.).

Soaker Hoses

Soaker hoses are porous tubes that, when laid on or slightly buried beneath the soil, release water slowly along their entire length. By targeting the root zone directly, they effectively reduce water loss due to evaporation and runoff. Soaker hoses are especially well suited for garden beds and borders, where uniform moisture is critical for healthy plant growth (Quickcrop, n.d.).

Pneumatic Systems

Pneumatic systems utilize air pressure and sensors to automate water delivery. In these systems, a bay sensor detects water levels; once a predetermined level is reached, the sensor pressurizes air, triggering the opening or closing of irrigation valves. These systems are generally installed as permanent solutions and are particularly useful for larger-scale operations where continuous monitoring is challenging (Victoria Government, n.d.).

Portable Timer Systems

Portable timer systems offer flexibility by allowing the irrigation control unit to be moved as needed. They use electronic clocks to regulate the opening and closing of irrigation structures. Their portability makes them ideal for temporary installations or for gardeners who wish to modify their watering setup seasonally (Victoria Government, n.d.).

Self-Watering Containers

Self-watering containers integrate an internal reservoir that automatically supplies water to plants. This design is especially beneficial for urban gardeners or those with limited space. By providing a consistent moisture supply, these containers reduce the need for frequent manual watering, promoting steady plant growth and reducing drought stress (How to culinary herb garden, n.d.).

Watering Globe s

Watering globes, typically made of decorative glass, are inserted into the soil near plants. As the soil dries, the globes slowly release water, ensuring a gentle and consistent watering effect. These are best suited for individual potted plants or small garden arrangements, where they serve both functional and decorative purposes (How to culinary herb garden, n.d.).

Water Timers and Controllers

Enhancing any automated watering system, water timers and controllers add precision and convenience. They can be programmed to operate based on specific times or calendar dates, with features such as rain delays and short interval bursts. Advanced controllers may also offer remote connectivity, allowing users to monitor and adjust watering schedules in real time via smartphones (Quickcrop, n.d.; Pope Irrigation, n.d.).

Integration and System Combination

In many cases, integrating two or more of these systems can yield superior performance. For example, combining a recirculating irrigation system with a drip irrigation network can maximize water reuse while delivering water directly to plant roots. Similarly, pairing pneumatic systems with advanced water timers and controllers can facilitate highly responsive and efficient watering based on sensor data. Such combinations allow for tailored solutions that address the specific needs of diverse environments, enhancing overall water conservation, plant health, and operational efficiency.

a versatile framework for developing robust irrigation solutions that can be customized for various residential and agricultural applications.

Component of automated plant watering system.

Let's visualize a typical automated plant watering system. At the heart of it all is the Control Unit, often an Arduino UNO, which acts like the brain. It receives information from various Sensors. The Soil Moisture Sensor is crucial, buried in the soil to constantly check how wet or dry it is. Some systems also include a **Soil** Fertility Sensor to monitor nutrient levels, and a Temperature Sensor because temperature affects how much water plants need. A Water Level Sensor in the Water Reservoir ensures the system doesn't run dry.

Based on the data from these sensors, the Control Unit activates the Actuators. The Water Pump, either submersible or surface-mounted, draws water from the reservoir. A Valve or Relay then controls the flow of water to the plants, turning the water supply on and off as needed.

Powering all of this can be done via a standard power adapter, or, for off-grid applications, Photovoltaic Panels can provide renewable energy, potentially coupled with a Battery Backup **to** ensure operation during power outages. Finally, all these components are connected by Wiring and Connectors, ensuring seamless communication and power flow. This integrated system allows for efficient and automated watering, tailored to the specific needs of the plants. Features like remote monitoring and control via Wi-Fi or other communication modules could be considered in future system enhancements.

Design Considerations

based on sensor feedback involves several key design considerations to ensure optimal water delivery and system durability. Critical factors

include evaluating the watering needs based on plant type, growth stage, and environmental conditions; ensuring proper sensor placement to accurately monitor soil moisture at various depths; and selecting a watering mechanism—such as a drip or sprinkler system—that is appropriate for the garden layout and water delivery requirements. Power supply options, including battery backups or solar panels, must be assessed to guarantee reliable operation in outdoor settings.

Performance Evaluation and Optimization.

Evaluating the performance of automated wagering systems is essential to ensure efficient water use and improved plant health. Key metrics include water efficiency—the reduction in water waste compared to manual methods, plant health—monitored via growth rates, leaf vitality, and soil quality, and reliability—the consistency of sensor readings and system responses under varying conditions. Optimization involves fine-tuning system components, such as calibrating soil moisture sensors for enhanced accuracy, refining watering schedules based on plant needs and environmental factors, and improving water delivery mechanisms to reduce losses. Both computational modeling and experimental testing are critical in predicting system behavior and validating performance improvements

Economic Analysis and Market Trends

In assessing the economic viability of an automated plant watering system, it is essential to examine several cost factors. The initial investment includes expenses for sensors, pumps, water storage, and installation of plumbing and wiring. Ongoing operational costs—such as power consumption, maintenance, and water supply—must also be considered, alongside the potential labor savings achieved by reducing manual watering. Evaluating these elements helps determine the system's payback period and return on investment, particularly when increased plant yields and water efficiency are factored in (Taira & Agyenim, 2019; Duffle & Beckman, 2013).

Market trends further reinforce the potential success of these systems. Growing environmental awareness and the push for sustainable resource management have heightened consumer interest in water-conserving technologies. Additionally, the rise in urban gardening and the expansion of Agri-Tech investments create a favorable environment for the adoption of automated watering solutions. While integration with internet of things (IOT) and smart home platforms is an emerging trend, the core focus remains on delivering cost-effective, reliable, and eco-friendly systems that meet consumer expectations for ease of use and efficiency.

By combining a robust economic framework with insights into current market dynamics, stakeholders can better position automated plant watering systems for success. Understanding these trends is crucial for developing competitive pricing strategies and ensuring the system's scalability—from individual home gardens to large-scale agricultural operations—thus paving the way for broad market acceptance and sustainable growth.

Environmental Impact and Sustainability

The implementation of an automated plant watering unit based on real-time soil moisture monitoring offers significant environmental impacts and sustainability benefits. By continuously assessing soil moisture levels, the system ensures precise and timely watering, promoting optimal plant growth while conserving water. This targeted irrigation approach can reduce water usage by 30-50% compared to traditional methods, which often lead to over watering and soil water-logging. Minimizing water waste not only preserves vital resources but also mitigates soil erosion by preventing excessive water application, thereby maintaining soil structure and health for long-term agricultural viability.

From a sustainability standpoint, the system enhances plant resilience by maintaining ideal moisture conditions, which supports healthier growth and improves yields, particularly in water-scarce conditions. This contributes to food security, a critical component of sustainable agriculture. Additionally, the system's design allows for integration with renewable energy sources, such as solar power, further reducing the carbon footprint and dependence on non-renewable energy. This integration aligns with global efforts to promote eco-friendly agricultural technologies.

The scalability and adaptability of the automated watering unit make it suitable for diverse environments, ranging from home gardens and community green spaces to large-scale agricultural fields. This flexibility enables widespread environmental benefits across various ecosystems, supporting broader sustainability initiatives.

In conclusion, the automated plant watering unit with real-time soil moisture monitoring demonstrates substantial environmental and sustainability advantages. By enhancing water efficiency, supporting plant resilience, and enabling renewable energy use, this solution addresses key challenges in resource management and climate change. Its adoption can play a vital role in advancing sustainable agriculture and responsible water management practices globally.

Challenges and Future Directions

The automated plant watering unit based on real-time soil moisture monitoring for optimal plant growth presents several challenges while opening avenues for future exploration and improvements in agricultural and horticultural practices. Despite its potential benefits in enhancing water efficiency and promoting healthy plant growth, the adoption of this technology is not without obstacles.

One of the primary challenges lies in technology adoption, as some farmers and gardeners may be hesitant to embrace new systems, particularly those unfamiliar with technological solutions. Limited technical knowledge regarding the operation and maintenance of automated watering units can hinder widespread use. Addressing this issue requires comprehensive education and training to ensure users can confidently operate and maintain the system. Another significant hurdle is the initial investment cost. Although long-term benefits, such as water savings and improved plant yields, are evident, the upfront expenses associated with system installation may discourage small-scale farmers or budget-conscious users. Financial support mechanisms, including subsidies or low-interest loans, could help mitigate these concerns.

Maintenance and technical support also pose notable challenges, especially for components exposed to harsh environmental conditions. Regular upkeep and the availability of replacement parts are essential to ensure consistent system functionality, which can be particularly difficult in remote areas. Additionally, reliance on technology introduces vulnerabilities; malfunctioning sensors or unexpected failures could disrupt the watering process, potentially harming plant health. Building robust systems with redundancy measures is crucial to minimize such risks. Environmental factors, including unpredictable weather events like floods or droughts, further complicate the consistent performance of automated watering units. Designing adaptable systems that can withstand varying conditions is vital to maintain productivity.

Looking toward the future, several opportunities can enhance the effectiveness and accessibility of the automated plant watering unit. Incorporating smart technologies, such as predictive analytics and data-driven decision-making, can optimize watering schedules based on historical soil moisture patterns and local climate trends. Though the current design emphasizes real-time monitoring, future models could further improve resource efficiency through integration with weather forecasts or adaptive

watering algorithms. Sustainability practices also offer a promising direction. Combining the system with rainwater harvesting could enhance water management, particularly during wet seasons, thereby contributing to broader conservation efforts.

Exploring modular design options could provide flexibility, allowing users to customize and scale the system according to specific needs and financial capacities. Such adaptability could increase adoption rates across diverse agricultural and gardening contexts. Additionally, ongoing research and development are essential for refining sensor accuracy, improving durability, and reducing system costs. Collaborations with research institutions, agricultural organizations, and technology developers can foster innovation and accelerate the creation of more effective and accessible solutions.

In conclusion, while the automated plant watering unit offers significant advantages in promoting water efficiency, optimal plant growth, and sustainable agricultural practices, overcoming challenges related to user adoption, initial costs, and system reliability is critical for widespread implementation. Future advancements, including enhanced technology integration, modular designs, and continued research, can further refine the solution, ensuring that it meets the evolving needs of both small-scale gardeners and large-scale agricultural producers.

Materials and Method

Efficient water management stands as a cornerstone of sustainable agriculture and conscientious plant care. Traditional irrigation methods, often reliant on manual judgment, frequently lead to either excessive or insufficient watering, both of which negatively impact plant growth and resource conservation (FAO, 2020). As noted by Raoetal. (2023), precision irrigation is crucial in mitigating these challenges. In response, this study focuses on the design, development, and implementation of an automated plant watering unit based on real-time soil moisture monitoring. The primary objective is to optimize plant hydration, enhance water use efficiency, and reduce labor-intensive watering practices.

This chapter details the design, development, and implementation of a system that ensures efficient water use, improves plant health, and minimizes manual intervention. By automating the irrigation process, the system ensures that plants receive water precisely when needed, thus promoting healthy growth while conserving water resources. This solution is particularly relevant in addressing global concerns about water scarcity and the increasing demand for sustainable agricultural technologies, aligning with recent systematic reviews on technologies aimed at optimizing water consumption in agriculture (2023).

The automated plant watering system integrates a capacitive soil moisture sensor (v1.2), which provides durable and corrosion-resistant soil moisture data acquisition, with an ESP32 micro-controller board. The ESP32, acting as the system's core processor, interprets the sensor data and executes control algorithms to manage water delivery. This system also incorporates a 12V DC solar power supply system, enabling off-grid operation and promoting environmental sustainability, and a 12V DC solenoid valve (normally closed), controlled by a 5V relay module (single channel), for precise water regulation. The inclusion of a 16x2 LCD display with I2C module allows for real-time monitoring of soil moisture levels and system status.

This chapter further highlights the hardware and software integration processes, detailing the physical assembly, wiring connections, and enclosure setup for outdoor deployment. The software implementation, including moisture reading and calibration, decision-making algorithms, and LCD display data updates, is also discussed. Moreover, the testing methods employed to ensure component functionality and system reliability, including soil moisture sensor accuracy, solenoid valve operation timing,

and power supply efficiency, are outlined. The overall working principle of the system, including the flowchart of operations and the challenges and design considerations addressed, is presented in a comprehensive manner.

This chapter aims to provide a clear and detailed account of the design and implementation process, demonstrating how the integration of these components and processes culminates in an effective and sustainable automated plant watering solution.

System Overview

The automated watering system monitors soil moisture and waters plants only when necessary. The capacitive soil moisture sensor sends data to the ESP32 micro-controller, which analyzes the moisture levels. If the soil is too dry, the system activates a solenoid valve through a relay module, allowing water to flow from a 10-liter reservoir via silicone tubing. Power is supplied through a solar panel connected to a rechargeable battery, ensuring continuous and eco-friendly operation. Real-time information, including moisture readings and system status, is displayed on a 16x2 LCD screen.

Components Used

The Capacitive Soil Moisture Sensor (v1.2) measures how wet the soil is without rusting. It sends out a signal that changes based on the amount of water in the soil. This helps keep plants from getting too much or too little water, which is important for them to grow well.

ESP32 Micro-controller: The ESP32 Micro-controller is the system's brain. It takes information from the soil moisture sensor and uses it to decide when to turn the water on or off. It controls the relay and solenoid valve, which manage the water flow. The ESP32 also has built-in Wi-Fi and Bluetooth, which could be used for adding more features to the system later. Its dual core processor allows it to perform multiple tasks at the same time, making it very responsive.

12V DC Solenoid Valve (Normally Closed): The 12V DC Solenoid Valve controls the water flow. It opens when the system needs to water the plants and closes when the soil is wet enough. This stops over-watering and makes sure water is used efficiently.

5V Relay Module (Single Channel): The 5V Relay Module acts as a safety switch between the ESP32 micro-controller and the solenoid valve. It allows the ESP32 to control the valve without risking damage to the circuit, safely switching the high-voltage component and ensuring reliable operation.

16x2 LCD Display with I2C Module: Shows real-time moisture levels and system operation status. The I2C module reduces wiring complexity, making the design neat and easy to manage.

Solar Power Supply: Comprises a 12V, 10W solar panel and a 7Ah rechargeable battery. This setup powers the entire system, ensuring sustainable and uninterrupted operation.

Flexible Silicone Tubing (1/2 inch): Transports water from the reservoir to the plants, ensuring a leak-proof flow.

10L Water Reservoir: Serves as the water source for irrigation during testing and practical use.

Weather-Resistant Enclosure: Protects electronic components from environmental conditions like rain and dust.

Breadboard and Jumper Wires: Facilitates prototyping and easy connection between components during the development stage.

System Design Process

1 Hardware Integration

The hardware setup started with prototyping on a breadboard. The soil moisture sensor was connected to the ESP32's analog input, while the relay module was linked to the ESP32's digital output pins to control the solenoid valve. The valve was connected to the water reservoir using silicone tubing, ensuring smooth water delivery. The solar power system included a 12V panel connected to a

rechargeable battery with a voltage regulator to supply 5V to the micro controller and display.

Software Development

The ESP32 was programmed using the Arduino IDE. The code continuously reads moisture levels and compares them to a predefined threshold. If the soil moisture is below the threshold, the relay activates the solenoid valve to water the plant. Once the soil reaches the desired moisture level, the valve shuts off. The LCD screen displays the moisture readings and watering status for user monitoring.

Testing and Calibration

Testing was done in phases to ensure proper functionality:

Component Testing: Verified the functionality of each hardware component separately.

System Calibration: The soil moisture sensor was tested with dry, moist, and saturated soils to determine accurate readings. The solenoid valve's response time was adjusted to prevent over-watering.

Field Trials: The fully assembled system was tested in a controlled environment to evaluate its performance under varied conditions. To simulate real-world scenarios, multiple plant containers with differing soil types (sandy, loamy, and clay) were utilized to assess the system's adaptability. Flow restrictors were incorporated into the tubing to regulate water delivery, preventing soil disturbance and potential root damage. Over a two-week period, moisture levels were meticulously monitored, comparing the automated watering outcomes against traditional manual irrigation. Data pertaining to water consumption, plant health indicators, and soil moisture consistency were recorded. This comprehensive evaluation aimed to determine the system's effectiveness and reliability in a controlled setting

Flow of Operations

The system's operation begins with the **solar power supply** providing consistent energy to all components. The **capacitive soil moisture sensor** then detects the current moisture level and sends the data to the **ESP32 micro-controller**. The ESP32 compares this reading to a predefined threshold. If the moisture level is below the threshold, the ESP32 signals the **relay module** to activate the **solenoid valve**, allowing water to flow from the reservoir. Concurrently, the **LCD display** updates in real-time, indicating that watering is in progress. Once the soil moisture sensor detects sufficient moisture, the ESP32 deactivates the relay, closing the solenoid valve and halting water flow. The system then returns to its monitoring state, continuously checking soil moisture levels and maintaining a stable power supply for optimal operation
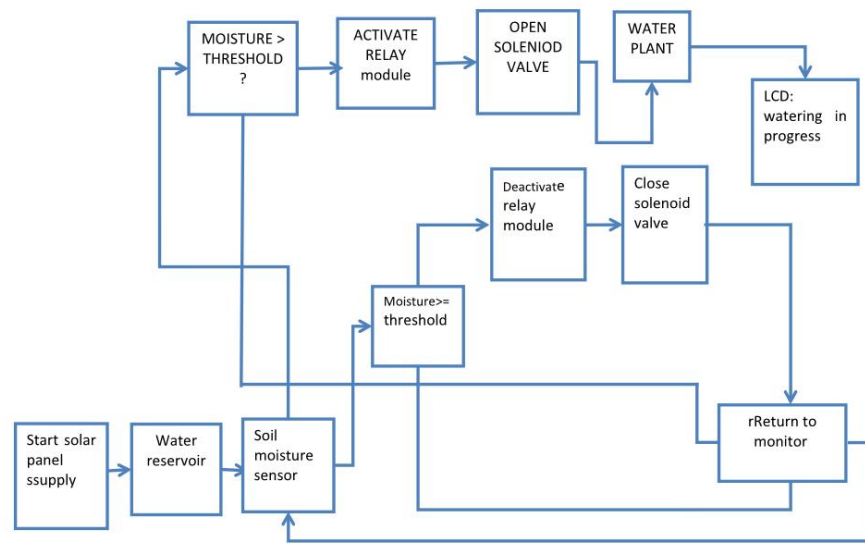
Challenges and Solutions

Delayed Sensor Response: Addressed by re-calibrating the sensor and adding flow restrictors.

Complex Wiring: Reduced complexity by using the I2C module for the LCD display.

Power Management: Optimized the solar panel and battery to ensure uninterrupted power supply.

Potential Root Damage: Controlled water flow to prevent excessive watering and soil erosion.

Bill of Engineering Measurement and Evaluation

S/N	Components	Quantity	Price
1	ESP32-micro-controller	**1**	N11,000
2	12V dc solenoid valve	**1**	**N45,000**
3	5V Relay module (single channel)	**1**	**N4,500**
4	16X2 LCD Display with 12C module	**1**	**N9000**
5	Solar power supply	**1**	**N40,000**
6	Flexible silicone tubing (1/2 inch)	**3**	**N3,500**
7	10L water reservoir	**1**	**N5000**
8	Weather resistance enclosure	**1**	**N35,000**
9	Breadboard and jumper wires	**1**	**N4,500**

		Total	N161,000

References

A review on hydroponics and technologies associated for medium- and small-scale operations. (2022). *Sustainable Agriculture Reviews*, 54, 112–130.

Astutiningtyas, M. B. I., Nugraheni, M. M., & Suyoto, S. (2021). Automatic plants watering system for small garden. *International Journal of Interactive Mobile Technologies (iJIM), 15*(02), 200–207. https://doi.org/10.3991/ijim.v15i02.19689

Divani, P., & Patil, A. (2018). *Automated plant watering system*. Semantic Scholar.

Duffle, J., & Beckman, R. (2013). Fabrication techniques in sustainable system design. *Journal of Sustainable Engineering, 5*(2), 45–59.

Joaquin, A. C., Santos, B. M., & Lim, L. G. (2020). Smart irrigation systems in agriculture: A systematic review. *Computers and Electronics in Agriculture, 176*, 105636. https://doi.org/10.1016/j.compag.2020.105636

Rao, P. S., Miller, J. K., & Thompson, Y. A. (2023). A review of precision irrigation water-saving technology under changing climate for enhancing water use efficiency. *Agronomy, 13*(5), 1350. https://doi.org/10.3390/agronomy13051350

Taira, K., & Agyenim, F. (2019). Design considerations in automated systems. *International Journal of Advanced Manufacturing Systems, 22*(1), 88–102.

Technologies to optimize the water consumption in agriculture: A systematic review. (2023). *Water Resources Management, 37*(8), 3015–3032.

Uzić, N., & Đumić, D. (2017). Automatic plant watering system and its applications. *Collegium Antropologicum, 41*(2), 169–172.