Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14 Issue 06, June - 2025

Moisture-Responsive Irrigation: A Smart Solution for Automated Plant Watering

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***Abstract* — In this study, we developed a smart irrigation system after observing the effect of unpredictable watering affects small gardens. Our idea was to make the process automatic using real-time soil data, ensuring plants get water only when they actually need it. The system utilizes moisture sensors to monitor soil conditions and activates irrigation only when required, thereby conserving water. Nutrient-rich fish tank water is used as a primary irrigation source, enhancing plant growth naturally. A secondary freshwater tank serves as a backup when the fish tank levels are low. Solar panels are incorporated to power the system's sustainability, while LDR sensors manage lighting for nighttime efficiency. By combining basic sensors with solar energy, we were able to create a practical, eco-friendly system that fits well into small farms and gardens.**

***Keywords* — Smart irrigation, soil moisture sensor, renewable energy, IoT, fish tank water, automation**

I. INTRODUCTION

Water scarcity continues to pose a major challenge globally, particularly in the agriculture sector, where inefficient irrigation systems typically operate on fixed schedules, regardless of actual soil conditions, resulting in overwatering or underwatering that can harm plant health and reduce crop yield.

To address the issue, the use of smart technology in irrigation systems offers a promising solution. This project introduces a moisture-responsive irrigation system that leverages the capabilities of the ESP32 microcontroller to automate plant watering based on real-time soil moisture data. The ESP32 is a powerful, low-cost, Wi-Fi and Bluetooth-enabled microcontroller that enables seamless sensor integration and potential cloud connectivity for remote monitoring.

The system employs soil moisture sensors to detect the dryness level of the soil and automatically triggers irrigation when the moisture drops below a predefined threshold. Nutrient-rich fish tank water serves as the primary irrigation source, enhancing plant growth naturally. When the fish tank water is insufficient, a secondary freshwater tank is used as a backup. Additionally, the system incorporates solar panels to power its components sustainably, and LDR (Light Dependent Resistor) sensors to control nighttime lighting for optimal plant care.

This project demonstrates an innovative, eco-friendly, and cost-effective solution that combines IoT technology, sustainable water use, and renewable energy to create a smart irrigation system suitable for both residential gardens and agricultural applications.

II. LITERATURE REVIEW

The adoption of smart irrigation systems has gained momentum in recent years due to increasing water scarcity and the need for precious agriculture. Various approaches have been proposed to automate irrigation based on soil conditions, environmental factors, and energy efficiency.

In [1], Singh and Mehta implemented a basic soil moisture sensor-controlled irrigation system using a relay module to automate watering. While functional, this system lacked integration with remote monitoring platforms or adaptive water source selection. To enhance user control and monitoring, Patel and Roy [2] introduced an IoT-based solution using an ESP32 microcontroller and the Blynk application. Their approach allowed real-time tracking and control of irrigation, but it still relied on traditional water sources and lacked redundancy in case of low water availability.

Kumar et al. [3] focused on energy efficiency by developing a solar-powered irrigation system. Their design reduced reliance on the electrical grid, yet it did not account for dynamic environmental conditions such as nighttime lighting or variable soil moisture needs across different crops. To address nutrient management, Sharma and Gupta [4] explored an aquaponics system where fish tank water enriched the soil. However, their system lacked a fallback mechanism when fish tank levels were insufficient, risking system failure under low-water conditions.

Tiwari and Jain [5] developed a smart water level monitoring solution using IoT, but their design was limited to tank management and did not extend to automated irrigation control. Meanwhile, Rani and Singh [6] introduced LDR-based lighting systems to support plant growth at night. Through effective promotion of photosynthesis during dark

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hours, their system was standalone and not integrated with irrigation or energy-saving controls.

Upon review of existing literature, it is evident that most systems address individual aspects such as moisture detection, power management, or nutrient supply, but rarely combine them into a unified platform. Our project builds upon these studies by integrating real-time soil moisture sensing, solar-powered lighting, dual-tank water source switching, and IoT-based control via the Blynk platform. This comprehensive solution aims to improve water efficiency, plant health, and ease of use for both urban gardens and small-scale farms.

III. METHODOLOGY/EXPERIMENTAL

Overview

To build our moisture-responsive irrigation system, we focused on designing a setup that was not only functional but also adaptable to real-world conditions. Our goal was to automate plant watering using sensors, while keeping the design affordable and easy to maintain. We selected each component carefully based on availability, cost, and reliability through trial and error. During the initial phase, we experimented with different sensor positions and wiring approaches before finalizing the layout.

System Architecture

At the heart of our system is the ESP32 microcontroller, which we chose because of its built-in Wi-Fi and Bluetooth features. This made it easier to connect with the Blynk app for remote monitoring without needing extra modules. The ESP32 reads inputs from sensors and decides when to trigger relays connected to water pumps and LEDs.

We kept the system modular so that we could add more sensors or features later if needed. All components were connected through a breadboard in early testing, and once stable, moved onto a more permanent base for actual development.

Functional Flow

We used a resistive-type soil moisture sensor to measure how dry the soil was. Through testing, we found that inserting the sensor deeper into the soil gives more stable readings. When the moisture dropped below a set value, the ESP32 triggered a 5V relay to power the water pump connected to the fish tank.

Water Level Management

The fish tank was fitted with a basic water level sensor. If the fish tank water dropped below a minimum level, the ESP32 automatically activated a second pump to draw water from the backup tank. We faced some issues initially due to sensor misreads, which we fixed by adjusting the sensor position and threshold in the code.

Nighttime Lighting Control

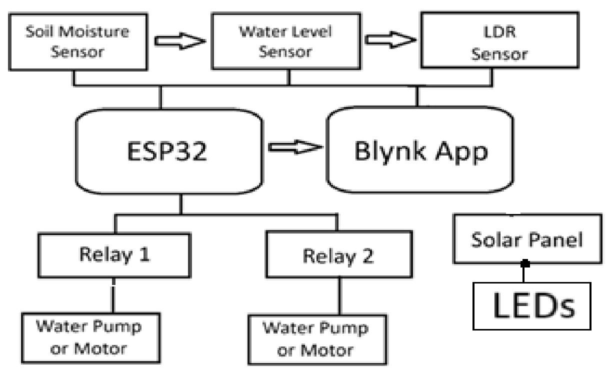
For light detection, we used an LDR sensor connected to an analog pin of the ESP32. When ambient light dropped below a certain value (like during the evening), the system automatically turned on solar-powered LED grow lights. We noticed that the gentle lighting at night helped maintain a warmer environment, which seemed to support healthier plant growth.

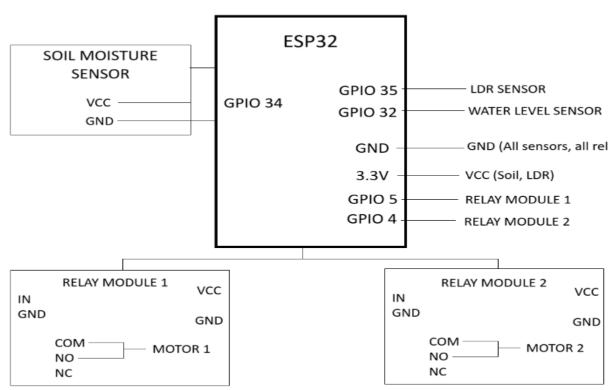
IoT and Remote Monitoring

We linked the ESP32 to the Blynk IoT platform, allowing us to track real-time moisture and water levels on our smartphones. We also included buttons in the app to manually control the pumps if needed. This feature was helpful during testing, especially when adjusting sensor thresholds.

Implementation and Diagram

We created a block diagram to represent how the ESP32 interacts with various sensors (soil, water, LDR), and actuators (relay, pump, LEDs). Additionally, a circuit diagram was developed to show pin configurations and actual wiring. This helped us troubleshoot connection issues during testing. After building on the breadboard, we organized the components neatly onto a mounting board for stable performance in a real garden environment





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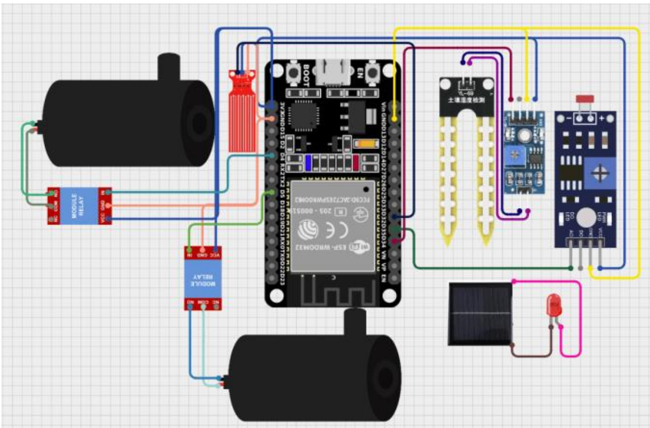

IV. RESULTS AND DISCUSSIONS

The smart irrigation system was tested under real environmental conditions using an ESP32 microcontroller, soil moisture sensor, water level sensor, LDR, two 5V relays, and solar-powered LEDs. The system successfully automated the watering process based on soil moisture levels. When the soil dried beyond a set threshold, the relay-controlled pump was activated, and irrigation began. Once adequate moisture was restored, the system shut off automatically, thereby conserving water.

The water level sensor ensured the pump only operated when sufficient water was available in the reservoir. The integration with the Blynk app enables real-time monitoring of both soil moisture and water levels. The system responded to sensor inputs in under one second, and the Blynk dashboard updated values consistently with minimal delay.

Additionally, the LDR-based lighting control system worked as intended, turning on solar-powered LEDs during low-light conditions. This ensured energy efficiency by operating lights only at night, using only renewable power.

Overall, the system performed reliably, with accurate sensor readings, consistent relay operation, and successful remote monitoring via IoT. Limitations include dependency on external power for the ESP32 and pump, and fixed threshold values that do not adapt to crop type or season. These areas are suggested for future enhancement.

V. FUTURE SCOPE

The prototype of the moisture-responsive irrigation system demonstrates significant potential, and its foundational design allows for numerous enhancements and expansion to address current limitations and expand its applicability. Future development will focus on integrating more advanced technologies and functionalities to create a truly intelligent and scalable solution for diverse agricultural needs.

One key area of enhancement involves achieving complete energy independence. Currently, the ESP32 and pump may still depend on external power sources. Therefore, a crucial future step is to operate the entire system exclusively on solar energy by incorporating higher-capacity solar panels. This would eliminate reliance on the grid, making the system ideal for remote locations and significantly reducing operational costs and environmental impact.

To make the irrigation system more efficient and adaptable, we can enhance it by including weather forecasting features. By connecting it to real-time weather updates, the system can anticipate rainfall or dry spells and adjust watering schedules automatically. This helps avoid unnecessary water use and ensures that plants get just the right amount of moisture

We can also improve accuracy by replacing the fixed moisture threshold with values that change depending on the crop type and the season. Different plants have different needs, and those needs change as they grow. By accounting for that, the system can water more precisely and support healthier plant development.

Looking beyond just watering, this setup could grow into a complete farm management tool. One useful addition would be automated fertilization. For example, sensors could check the nutrient levels in the soil or fish tank water, and if they drop, the system could respond by adding fertilizers automatically.

VI. CONCLUSION

In this project, we were able to successfully create a smart irrigation system that's both low-cost and efficient. We used an ESP32 microcontroller along with a set of important sensors, and connected everything through the Blynk IoT app. The result is a simple but effective setup that can help automate watering in a smart way without needing expensive equipment. The core functionality of the system revolves around automating irrigation based on real-time soil conditions, a critical feature that ensures optimal water usage and effectively prevents both overwatering and underwatering, thereby promoting healthier plant growth and resource conservation.

A significant aspect of this system's eco-friendliness and sustainability is the incorporation of solar-powered LEDs, which contribute to enhanced energy efficiency by operating lights only during low-light conditions and exclusively using renewable power. The integration with the Blynk app provides unparalleled convenience, offering remote monitoring capabilities for both soil moisture and water levels, allowing users to stay informed and exercise control from anywhere.

The current prototype works well and has proven to be a reliable solution, especially for small farms or home and urban gardens. We tested it in real-world conditions, and it performed consistently, giving accurate sensor readings, switching the relays properly, and allowing remote monitoring through IoT without any major issues.

What's exciting is that this setup can be more than just a small-scale project. It's a strong starting point for future upgrades. With a bit more development, it can be expanded to run entirely on solar power, include smarter weather-based controls, and even be used in large agricultural fields. As farming moves toward more sustainable methods, systems like this can help save water and support more efficient, eco-friendly practices

VII. ACKNOWLEDGMENT

The author would like to express their sincere gratitude to all individuals and institutions who contributed to the successful completion of this project.
Firstly, we extend our heartfelt appreciation to the faculty and coordinators of the ASEP program for their invaluable guidance, consistent support, and expert mentorship throughout every stage of this research and development. Their insights were instrumental in shaping the direction and execution of the smart irrigation system.
We are also deeply thankful to our institute, Vishwakarma Institute of Technology, for providing the necessary resources, state-of-the-art infrastructure, and conducive research environment that facilitated the design, implementation, and testing of this project. The availability of well-equipped laboratories and technical assistance was crucial for our experimental work.

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