

Design and Development of a Real-Time Soil Moisture Monitoring-Based Automated Plant Watering Unit for Ideal Growth

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Abstract

That is where this project, which demonstrates an automated plant watering system which enables real-time soil moisture monitoring to ensure that plants are hydrated when they need it most comes in. After the soil moisture is below a set threshold, then system is to automatically water. Soil moisture is monitored using soil moisture sensors. The system ensures efficient water usage, promote vigorous plant growth and save on water resources at the same time. Created as an economic and free type device, the vehicle applies to any use scenes such as home gardens, public green areas, farm facilities and so on. It also is an effective way to better care for plants and save water by being versatile and focusing on conservation.

1. Problem Statement

The water management that does not work well still causes a problem, for farms and gardens today because the watering techniques that people use often rely on opinion. The watering techniques often give water or not enough water. The much water or not enough water can hurt the plant health. The much water or not enough water can lower the soil fertility. The much water or not enough water can waste the water resources. The water management problems also stop the plant growth. The water management problems also cause the deterioration. The water management problems also raise the labor costs. I see that automated plant watering systems have solved some of the problems. The current solutions lack cost effectiveness. The current solutions lack real time responsiveness. The current solutions lack user friendliness. The lack of cost effectiveness the lack of real time

responsiveness and the lack of user friendliness stop the adoption.

This work is a creation of an automated plant watering system that does real time soil moisture monitoring so the plants grow well. I built the automated plant watering system. The automated plant watering system removes guessing. Cuts water waste, by checking the soil moisture and deciding when watering is needed. Compared to systems the automated plant watering system focuses on accuracy and works well by giving the amount of water at the right time to keep the plants in good condition. Its design prioritizes economy and ease of use, making it suitable for a range of uses, from huge agricultural settings to small-scale home gardens.

In addition, to saving water the automated unit helps plant health by stopping problems that happen when watering is wrong such, as plants wilting from drought or roots rotting from much water. The automated unit keeps soil moisture steady so the plants become stronger. Grow roots. I have seen that the automated unit can work in gardens or large farms. The automated unit can work with kinds of plants. Can fit in different places. By eliminating the need for continuous manual monitoring and watering, this approach not only helps conserve water but also lessens the labor-intensive aspects of traditional plant care.

The automated plant watering device contributes significantly to overall concerns about resource management and environmental sustainability by promoting sustainable watering practices. In both agricultural and horticultural contexts, its

application becomes a major step toward more effective, efficient, and environmentally friendly plant care solutions.

2. Literature review

Effective water management is essential for both home gardening and agriculture due to the growing stresses of climate change, fast urbanization, and water scarcity.

By providing precise amounts of water when needed, automated plant watering systems present a possible answer. The design of automated plant watering devices based on real-time soil moisture monitoring is the main topic of this literature review. It examines how these systems can maximize plant growth, conserve water, and minimize manual labor—all of which ultimately support sustainable practices.

These technologies have become essential in contemporary horticulture by tackling ineffective water management, as [7] notes. By tackling ineffective water management, these methods have become essential to contemporary horticulture. This analysis looks at the main components and design principles of such units, including the integration of soil moisture sensors, control mechanisms, and water delivery systems. [3, 4] highlight the benefits even for small-scale gardens, where automation saves time and sustains optimal growth.

Responsive water distribution that follows the soil conditions works because we use sensor technologies and micro-controllers, like Arduino [1 2]. Responsive water distribution can also use internet of things (IOT) components such as monitoring through applications [6]. Responsive water distribution will be used in settings. The primary functionality of the units will stay the focus. [7] highlight the substantial water-saving benefits of precision irrigation, and recent systematic assessments highlight the long-term financial advantages, such as lower labor and resource costs.

3. Overview of automated plant watering systems

Advanced technologies called automated plant watering systems are made to continuously check the moisture content of the soil and release water as necessary. Their main goal is to guarantee that plants get the right amount of

water, which is essential for their well-being and productivity. These devices considerably lower the possibility of human error by automating the watering process, avoiding both overwatering and underwatering. This results in more stable growing conditions, which are necessary to maximize production and encourage healthy plant growth.

4. Types of Automated Plant Watering Systems

Automated plant watering systems have developed into a wide range of technologies, each designed to satisfy certain agricultural and gardening requirements. This takes into account many kinds of systems, looks at their special advantages and applicability for diverse settings, and investigates the possibility of combining two or more systems for improved performance.

5. Recirculating irrigation

The purpose of recirculating irrigation systems is to mimic the natural water cycle. In these systems, water is pumped to the top of a vertical planter from a storage tank. The water irrigates the plants as it seeps through each pot, then it is collected back into the tank for reuse. Compared to traditional methods, this closed-loop system can save over half of the water and nutrients. Installing digital or Wi-Fi timers allows for precise scheduling, ensuring that each plant gets the right amount of water [7, 8].

6. Drip irrigation

With a system of tubes fitted with tiny drippers, drip irrigation delivers a measured, slow feed of water right to plant roots. It is also a great way to efficiently utilize water, avoiding both evaporation and runoff. Drip irrigation can be utilized with many types of plants and any garden type.

Pressure-compensated drippers are recommended for vertical gardening to provide uniform watering conditions for all the plants. This approach is suitable for widespread agricultural machine use and for home gardens; the integration of a timer refines further the schedule [5, 2].

7. Capillary irrigation

Capillary irrigation is the use of capillary action to water plants. This gadget constantly supplies the soil with a low level of moisture from water pulled up through a wick from a reservoir. This is very useful in the case of indoor plants or a mini garden that would require constant watering without being overly watered [6, 7].

8. Sprinkler systems

Sprinkler systems are designed to spread water over a large area, mimicking the way natural rainfall occurs. They're commonly used in expansive agricultural fields, lawns, and gardens. These systems consist of interconnected pipes and sprinkler heads, including pop-up models that retract when not in use to avoid damage. However, even with their extensive coverage, factors like wind drift and evaporation can reduce their effectiveness, especially in dry climates.

9. Soaker hoses

Soaker hoses are these nifty porous tubes that release water slowly along their entire length when you lay them on the ground or just below the surface. They do a great job of minimizing water loss from evaporation and runoff by targeting the root zone directly. Since keeping plants consistently hydrated is key for their growth, soaker hoses are a fantastic choice for garden beds and borders [3].

10. Systems using pneumatics

Pneumatic systems are a smart way to automate water delivery, utilizing sensors and air pressure to get the job done. They feature a bay sensor that keeps an eye on water levels; once it hits a certain point, the sensor activates air pressure, which in turn opens or closes irrigation valves. For larger businesses where keeping a constant watch is tricky, these systems can be a game changer, as they're usually set up as permanent fixtures [7].

i. Portable timer systems

The great thing about portable timer systems is their flexibility; you can easily move the irrigation control unit whenever you need to. These systems use electronic clocks to manage when irrigation structures open and close. Their

portability makes them ideal for short-term setups or for gardeners who like to adjust their watering routines with the changing seasons, [5].

ii. Self-watering containers

Self-watering pots come with a built-in reservoir that automatically supplies water to your plants. This setup is especially great for those with limited space or urban gardeners. By providing a steady stream of moisture, these containers reduce the need for constant manual watering, promoting healthy plant growth and easing the stress of drought.

iii. Watering

Watering globes, often made of beautiful ornamental glass, are designed to be placed in the soil next to your plants. They slowly release water as the soil dries out, creating a gentle and consistent irrigation effect. These globes are especially effective in small garden setups or individual potted plants, serving both a decorative and practical purpose.

iv. Water timers and controllers

Water timers and controls really enhance the precision and convenience of any automatic watering system. They come with handy features like rain delays and short bursts of water, allowing you to set them to operate at specific times or on certain dates. Plus, more advanced controllers can even connect to your smartphone, giving you the ability to check and adjust your watering schedules in real time [4].

11. Integration and system combination

Mixing and matching different irrigation systems can really boost their performance. For example, if you combine a drip irrigation setup with a recirculating system, you can make the most of water reuse while delivering it right to the roots of your plants. Likewise, by pairing pneumatic systems with advanced timing and control features, you can achieve super responsive and efficient watering based on sensor data. These combinations allow for tailored solutions that enhance water conservation, promote plant health, and improve operational efficiency by meeting the specific needs of different environments. It creates a

versatile framework for developing reliable irrigation systems that can be customized for various residential and agricultural applications.

12. Component of automated plant watering system.

At the heart of a standard automated plant watering system is the control unit, often an Arduino UNO, which acts like the brain of the operation. It gathers data from various sensors, with the soil moisture sensor being a key player. This sensor is buried in the ground, constantly checking the moisture levels of the soil. Since temperature affects how much water plants need, many systems also include a temperature sensor and a soil fertility sensor to monitor nutrient levels. To prevent the system from running dry, there's a water level sensor in the water reservoir. The control unit uses the information from these sensors to activate the actuators. The water pump, which can either be mounted on the surface or submerged, draws water from the reservoir to keep the plants hydrated.

The water supply is managed by turning it on and off as needed, using a valve or relay that controls the flow to the plants. You can power this setup with a standard power adapter, or if you're going off-grid, solar panels can provide renewable energy, possibly paired with a battery backup to keep everything running during power outages. Finally, wiring and connectors link all these components together, ensuring a smooth flow of power and communication. This integrated system allows for efficient, automated watering tailored to the specific needs of each plant. Looking ahead, future upgrades could include features like remote monitoring and control through Wi-Fi or other connectivity options.

13. Design considerations

When it comes to designing an effective watering system, it is essential to consider various factors based on sensor input to ensure a reliable water supply and long-lasting performance. Selecting the right watering method, like a drip system, that fits your garden's layout and meets its water delivery needs is crucial. Additionally, evaluating the watering requirements based on the types of

plants, their growth stages, and the surrounding environmental conditions is key. Don't forget to thoroughly assess power source options, such as solar panels or battery backups, to guarantee consistent operation in outdoor settings.

14. Performance evaluation and optimization

Automated water systems really need a good assessment to make sure we're using water efficiently and keeping our plants healthy. We look at growth rates, leaf vitality, soil quality, and how well water is being used to keep an eye on how consistent the sensor readings and system responses are in different plant health scenarios. Key metrics to consider include how much water waste is cut down compared to traditional methods. When it comes to optimization, it's all about fine-tuning the system components—like calibrating soil moisture sensors for better accuracy, adjusting watering schedules based on what the plants need and the surrounding environment, and improving water delivery systems to minimize losses.

15. Economic analysis and market trends

Taking a closer look at various cost factors is essential when figuring out if an automated plant watering system makes financial sense. You need to consider the initial investment, which includes expenses for sensors, pumps, water storage, and the plumbing and electrical installations. Plus, while you might save on labor costs by reducing the need for manual watering, it's also important to factor in ongoing costs like electricity, maintenance, and water supply. By looking at these elements, especially when you consider the potential for higher plant yields and better water efficiency, you can get a clearer picture of how long it will take to recoup your investment and what kind of return you can expect [3, 4, 6].

The potential success of these solutions is backed by current market trends. More and more consumers are showing interest in water-saving devices, driven by a growing awareness of environmental issues and a push for sustainable resource management. The rise of automatic watering systems is also being supported by increased investments in agriculture and technology, along with the popularity of urban

gardening. While integrating with smart home platforms and the Internet of Things (IoT) is a relatively new trend, the main goal remains the same: to offer affordable, reliable, and eco-friendly systems that meet customers' needs for efficiency and ease of use.

Stakeholders can improve automated plant watering systems by combining a solid economic framework with an understanding of current market trends. To develop competitive pricing strategies and ensure the system's scalability—from individual home gardens to large agricultural operations—it is essential to understand these trends. This understanding will lead to wider market acceptance and sustainable growth.

16. Environmental impact and sustainability

Adopting an automated plant watering system that uses real-time soil moisture monitoring offers significant benefits for sustainability and the environment. The device ensures precise and timely watering, which promotes healthy plant growth while saving water by constantly checking soil moisture levels. This stands in contrast to traditional methods, which often lead to overwatering and soil waterlogging. With this system, water usage can be reduced by 30 to 50%. By preventing excessive water application, we not only protect essential resources, but we also lessen water waste, reduce soil erosion, and maintain soil health and structure for long-term farming success.

From a sustainability viewpoint, the technology improves plant resilience by maintaining optimal moisture levels. This leads to healthier growth and higher yields, particularly in areas with limited water supply. It contributes to food security, which is crucial for sustainable farming. Additionally, the system's design reduces carbon emissions and dependence on non-renewable energy. It allows for the use of renewable energy sources like solar power. This integration supports global efforts to promote environmentally friendly farming practices.

The automatic watering machine can be used in many settings, from large agricultural fields to home gardens and public parks. Its flexibility supports a range of environmental benefits across different habitats and helps larger sustainability efforts.

In summary, the automated plant watering system with real-time soil moisture monitoring offers significant environmental advantages. This system addresses key challenges in resource management and climate change by improving water efficiency, strengthening plant resilience, and allowing the use of renewable energy. Using this technology can greatly support sustainable agriculture and responsible practices.

17. Materials

One of the cornerstones of sustainable agriculture and nurturing healthy plants is smart water management. Traditional irrigation methods often rely on human judgment, which can lead to overwatering or under watering—both of which can harm plant growth and waste precious resources. That's where precision irrigation comes into play, as highlighted in studies [7, 8].

In this project, we're focused on designing, developing, and implementing an automated plant watering system that monitors soil moisture in real time. Our main goals are to optimize how we hydrate our plants, boost water efficiency, and cut down on those labor-intensive watering methods.

To dive into how a system that not only ensures efficient water use but also boosts plant health while cutting down on the need for manual labor was created. The technology takes the guesswork out of watering by automating the irrigation process, so plants get just the right amount of water exactly when they need it. This not only helps them thrive but also conserves precious water resources. With recent studies highlighting the importance of optimizing water use in agriculture, our approach is particularly relevant as we tackle global challenges like water scarcity and the increasing demand for sustainable farming solutions.

The automated plant watering system is a clever little setup that pairs an ESP32 microcontroller board with a durable capacitive soil moisture sensor (v1.2). This combination not only gathers reliable soil moisture data but also stands up to corrosion like a champ! The ESP32 acts as the brain of the operation, analyzing the sensor readings and using smart control algorithms to

make sure your plants get just the right amount of water. It's like having a green thumb, but with a techy twist.

This system also features a 12V DC solar power supply, making it perfect for off-grid use and environmentally friendly. Plus, it comes with a 12V DC solenoid valve that usually stays closed and is managed by a single-channel 5V relay module, ensuring precise water regulation. To keep you in the loop, there's a handy 16x2 LCD display with an I2C module that provides real-time updates on soil moisture levels and the overall status of the system.

This chapter covers in detail the physical assembly, electrical connections, and enclosure configuration for outside deployment, with an emphasis on the procedures for hardware and software integration. Additionally, there is more input of the software being implemented, which includes refreshing the data shown on LCD displays, decision-making algorithms, and reading and calibrating moisture.

Additionally, the testing techniques used to ensure system and component operational reliability included: soil moisture sensor accuracy, solenoid valve operating timing, and power supply efficiency. The general operating principle of the system is given in a comprehensive way with the flowchart of the operations, difficulties, and design factors addressed.

Clear explanation of the design and implementation processes has been elaborated to show how the combination of these elements and procedures results in an efficient and long-lasting automated plant watering solution.

18. System overview

The automated watering system waters the plants only when needed; it watches the moisture content of the soil constantly. Capacitive soil moisture sensor data is sent to the ESP32 microcontroller, where it reads and analyzes the present moisture levels of the soil. When the soil gets too dry, a solenoid valve is triggered by the system using a relay module, allowing water to flow from a 10-liter reservoir via silicone tubing. Power is supplied by a solar

panel coupled with a rechargeable battery, making this device work continuously while also being eco-friendly. A real-time representation of the current moisture level and system status is displayed on a 16x2 LCD.

i. Components used

Capacitive Soil Moisture Sensor-v1.2: This sensor measures the moisture of the soil without rusting. It sends out an analog signal that corresponds to the water content of the soil. This prevents plants from getting overwatered or underwaterd, which is very important for their healthy growth.

ii. Micro-controller-ESP32

The brain of the system is the ESP32 Microcontroller. It controls when to turn the water on or off, based on the data that it has collected from the soil moisture sensor. This regulates the solenoid valve and relay, which in return controls the water flow basically. Again, the ESP32 has incorporated Bluetooth and Wi-Fi, which can be utilized in expanding the functionalities of the system. It is highly responsive because of its two-core CPU, allowing it to multitask at once.

iii. solenoid valve-12V DC

a 12V DC solenoid valve controls the flow of water. It closes during conditions when the soil is sufficiently moist and opens when the system should water the plants. In this way, it ensures that water is used efficiently without causing overwatering.

iv. Relay module-5V

The 5V Relay Module works as a safety switch between the solenoid valve and the ESP32 microcontroller, which allows the ESP32 to control the valve for securely switching the high-voltage component to ensure dependable performance without running the risk of damaging the circuit.

v. 16x2 LCD display with I2C module

shows the instantaneous status of the system operating and moisture levels. Since the I2C module simplifies wiring, the design is neat and manageable.

vi. Solar power supply

comprises a 7Ah rechargeable battery and a 12V, 10W solar panel.

This configuration powers the entire system to ensure constant and sustainable operation.

vii. Flexible silicone tubing (1/2 inch)

ensures a leak-proof flow of water from the reservoir to the plants.

viii. 10L water reservoir

provides irrigation water for testing and real-world applications.

ix. Weather-resistant enclosure

shields electrical parts from external elements like dust and rain.

x. Breadboard and jumper wires

makes it easier to connect components throughout the development stage and makes prototyping easier.

19. System design process**i. Hardware integration**

For the hardware set-up, the breadboard prototype was the first step. The relay module was connected to the digital output pins of the ESP32, which can control the solenoid valve, while the soil moisture sensor was connected to its analog input. Silicone tubing was used to connect the valve to the water reservoir to ensure excellent water distribution. The solar power system consisted of a 12V panel connected to a rechargeable battery with a voltage regulator for providing 5V to the microcontroller and display.

ii. Software development

An Arduino IDE was used to program the ESP32. The code keeps checking the soil's moisture level and compares it to a set threshold. When the soil gets too dry, the relay flips on the solenoid valve and waters the plant. Once the soil hits the right moisture, the valve shuts off. The LCD screen shows you what is happening; watering status and real-time moisture readings so you always know what's going on.

iii. Testing and calibration

We tested everything in stages to make sure it all worked the way it should. Each piece of hardware got its own check. For the soil moisture sensor, we tried it out on dry, wet, and fully saturated soil to see how it performed. To stop the system from overwatering, we tweaked the solenoid valve's response time.

iv. Field trials

To see how the system really performed, so it was set up in a controlled space and put it through its paces. We filled several plant containers with different kinds of soil—clay, loamy, and sandy—to make things feel more like the real world and to check how flexible the system actually was. To make sure water got where it needed to go without disturbing the soil or damaging roots, we added flow restrictors to the tubing. Then, over two weeks, we kept a close eye on moisture levels, comparing how the automated watering stacked up against regular manual watering. We tracked soil moisture, plant health, and water use along the way. The whole point was simple: figure out if the system was reliable and did its job well under controlled conditions.

20. Flow of operations

First, the capacitive soil moisture sensor checks how wet the soil is and sends that info to the ESP32 microcontroller. The ESP32 looks at the reading and compares it to the set threshold. Everything runs on solar power, so all the parts get a steady stream of energy. If the soil's too dry, the ESP32 tells the relay module to open up the solenoid valve, letting water flow from the reservoir. The LCD screen updates right away, showing that watering has started. Once the soil gets enough moisture, the sensor lets the ESP32 know, and it shuts off the relay, which closes the valve and stops the water. Then the system goes back to watching the soil, always keeping an eye on moisture levels and making sure it has enough power to keep running smoothly.

21. Challenges and solutions

Recalibrating the sensor and installing flow restrictors are two ways to address delayed sensor response.

i.Complex wiring

using the I2C module for the LCD display simplified the wiring.

ii.Power management

to guarantee a steady supply of electricity, the solar panel and battery were optimized.

iii.Possible harm to roots

regulated water flow to avoid overwatering and soil erosion

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