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Automated irrigation system for rooftop gardening using IoT

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Abstract

Urbanization has led to a significant reduction in cultivable land, pushing cities to explore sustainable alternatives such as rooftop gardening to ensure local food production and green coverage. While rooftop gardening offers numerous environmental and social benefits, maintaining these gardens manually introduces several operational challenges. These include inconsistent watering schedules, overuse of water resources, inefficient nutrient distribution, and the increased time and labor required for maintenance. Such issues not only compromise plant health and yield but also reduce the overall efficiency and sustainability of urban gardening systems. To address these problems, this project presents a fully integrated Internet of Things-based automated irrigation system specifically designed for rooftop gardening applications. The proposed system employs a soil moisture sensor to continuously monitor the hydration status of the soil and electrical conductivity and total dissolved solids sensors to assess the concentration of essential nutrients in the irrigation water. A microcontroller serves as the system's central processing unit, analyzing sensor data in real time to determine whether irrigation or nutrient supplementation is required. Based on the sensor feedback, the microcontroller activates a water pump to deliver water and nutrients only, when necessary, thereby reducing waste and promoting optimal plant growth. The system is powered entirely by a solar panel, ensuring energy efficiency and eliminating dependency on the conventional power grid. It incorporates Bluetooth connectivity, allowing real-time monitoring and control via a user-friendly mobile application. Users can view moisture and nutrient levels, receive automated alerts, and even schedule irrigation cycles based on plant-specific requirements. This level of automation and remote control significantly reduces manual effort while enhancing precision in garden management. The design is scalable and cost-effective, making it applicable to a wide range of setups including rooftop gardens, vertical farms, and greenhouse operations. Initial testing has validated its functionality, reliability, and ease of use. The system has also been presented at an international conference, garnering interest for its innovative approach, and is currently undergoing the publication process. Overall, this project offers a practical and sustainable solution to improve food production in urban environments through smart gardening technologies.

Keywords: Rooftop gardening, automated irrigation system, IoT in agriculture, soil moisture monitoring, nutrient management, solar-powered irrigation

1. Introduction

The rapid pace of urbanization has significantly reduced the availability of arable land, prompting the need for alternative methods of sustainable food production. One such method, rooftop gardening, utilizes otherwise unused urban spaces to grow food locally, thereby enhancing food security and promoting environmental sustainability. In addition to providing access to fresh produce, rooftop gardens contribute positively to air quality, help mitigate urban heat island effects, and improve mental well-being among city dwellers. However, despite these benefits, maintaining rooftop gardens poses considerable challenges, particularly with respect to irrigation and nutrient management. Traditional irrigation methods in urban gardening are often manual, time-consuming, and inconsistent, resulting in over-watering or under-watering due to the absence of real-time feedback. Similarly, the manual application of nutrients without accurate measurement frequently leads to suboptimal plant growth, fertilizer wastage, and potential environmental harm. These limitations underscore the need for an automated, intelligent system capable of optimizing resource use while minimizing manual intervention.

In recent years, researchers have explored the application of smart technologies and Internet of Things (IoT) systems in agriculture to address such challenges. Automated irrigation systems equipped with sensors and controllers have shown promise in improving water efficiency and reducing labor in traditional farming. However, their application in the context of urban rooftop gardening remains limited, particularly in designs that integrate both water and nutrient management, renewable energy, and real-time user control. To fill this gap, the present project proposes a smart, IoT-based automated irrigation system specifically designed for rooftop gardening applications. The system incorporates soil moisture sensors to monitor hydration levels and TDS/EC sensors to assess nutrient concentration in the water. A microcontroller processes the sensor data and controls a water pump that activates only when necessary, ensuring precise water and nutrient delivery. The system is powered by solar energy, promoting sustainability and energy independence. Bluetooth connectivity and a mobile application enable remote monitoring, control, and notifications, enhancing user convenience.

This integrated solution aims to reduce water and energy consumption, minimize labor, and support healthier plant growth through data-driven management. By combining smart sensing, automation, and renewable energy, the system offers a scalable, cost-effective approach to modernizing urban rooftop gardening. It contributes to ongoing efforts in smart agriculture and presents a practical model for sustainable urban food production.

2. Materials and Methods

The following hardware and components were used in the development of the IoT-based automated irrigation system:

Component	Function
Soil Moisture Sensor	Detects the moisture level in the soil to determine if irrigation is needed.
TDS Sensor	Measures the Total Dissolved Solids in the water, indicating nutrient levels.
EC Sensor	Measures the Electrical Conductivity to monitor the concentration of dissolved ions.
Water Pump	Delivers water from the reservoir to the plants when activated.
Arduino/ESP32 Board	Microcontroller for processing sensor data and controlling other components.
Bluetooth Module (HC-05/06)	Enables wireless communication between the system and mobile app.
Rain Sensor	Detects rainfall and prevents unnecessary irrigation.
Solar Panel	Supplies power to the system, reducing dependency on external electricity.
Mobile Application	Interfaces with the system to display data and provide remote control options.

2.1 Methodology

1. **Step 1: Sensor Calibration and Placement**

- **Soil Moisture Sensor:** The soil moisture sensor is carefully inserted into the soil near the plant roots to ensure accurate measurement of moisture levels. This placement allows for precise data on soil hydration for optimal irrigation.
- **TDS and EC Sensors:** Total Dissolved Solids (TDS) and Electrical Conductivity (EC) sensors are submerged in the water reservoir to continuously monitor the nutrient content of the irrigation water. These sensors provide real-time data on the quality of the water and its suitability for plant growth.
- **Rain Sensor:** A rain sensor is placed in an open location, away from obstructions, to detect rainfall and ensure the system does not irrigate during precipitation, thereby conserving water resources.

2. **Step 2: System Integration**

- **Microcontroller Setup:** All sensors are connected to an Arduino or ESP32 microcontroller, which serves as the central unit for data processing and control.
- **Bluetooth Module:** The Bluetooth module is paired with a mobile application, allowing users to communicate with and control the system remotely.
- Water Pump Control: The water pump is connected to the microcontroller via a relay module, enabling controlled operation of the pump based on sensor inputs and programmed thresholds.

3. **Step 3: Programming and Automation Logic**

- The microcontroller is programmed using the Arduino IDE. Threshold Values: Specific threshold values are defined for system automation:
- When soil moisture falls below 30%, the water pump is activated to irrigate the garden and when TDS levels drop below 300 ppm or EC levels fall below 700 µS/cm, an alert is triggered for either manual or automatic nutrient addition to the irrigation water.
- Rain Sensor Logic: If rainfall is detected by the rain sensor, the irrigation system is skipped to avoid unnecessary water usage.

4. **Step 4: Power Supply Setup**

A solar panel with a charge controller is installed to power the system sustainably, using solar energy. A battery backup is integrated to store solar energy and ensure uninterrupted operation of the system during periods of low sunlight.

5. **Step 5: Data Communication and Control**

The sensors transmit real-time data on soil moisture, TDS, and EC levels to the mobile app via Bluetooth. Users have the option to view the current sensor readings, adjust irrigation schedules, and override the automatic system settings if needed.

6. **Step 6: Testing and Optimization**

The system is initially tested on a rooftop garden setup, where it undergoes multiple iterations to optimize sensor calibration, pump timing, and automation logic. Performance Evaluation: Data is logged to assess the effectiveness of the system, enabling performance evaluation and potential adjustments to improve system efficiency.

2.2 Flow Diagram

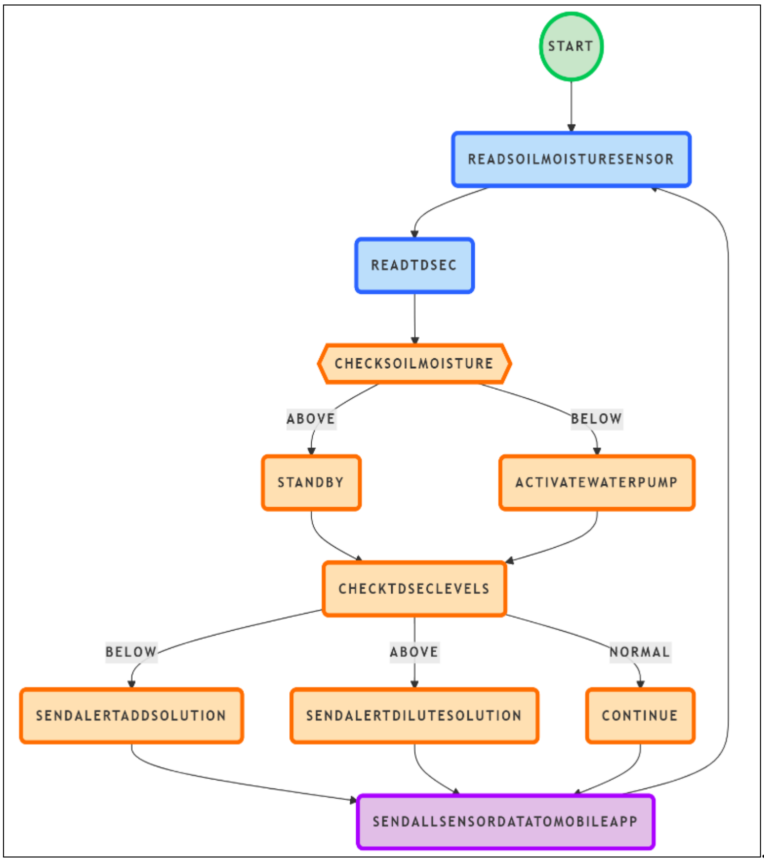

Fig 1: Flow Diagram

2.1 Cost Estimation

Component	Purpose	Estimated Cost (INR)
Arduino UNO / Node MCU (ESP32)	Core microcontroller to manage sensors and control the pump	₹300 - ₹600
Soil Moisture Sensor	Detects soil moisture to determine when watering is needed	₹50 - ₹150
Water Pump (Mini Submersible)	Pumps water from the reservoir to the plants	₹200 - ₹500
Relay Module	Switches the pump ON/OFF based on sensor data	₹100 - ₹150
TDS Sensor or EC Sensor	Monitors nutrient levels in the water	₹400 - ₹800
Tubing & Fittings	Distributes water from pump to plant beds	₹100 - ₹200
PCB or Breadboard & Wires	Connects and supports circuit setup	₹100 - ₹200
Solar Panel (10W-20W)	Powers the entire system independently, no external electricity required	₹500 - ₹1200
Bluetooth Module (HC-05/HC-06)	Allows local wireless control through a mobile app	₹100 - ₹150

Total: ₹1850 - ₹3950

3. Results and Discussion

The IoT-based automated irrigation system was successfully deployed and tested on a rooftop garden. During the testing phase, the system demonstrated effective functionality in all key areas, including soil moisture monitoring, nutrient management, rain detection, and energy efficiency. The soil moisture sensor consistently measured moisture levels in the soil, and irrigation was triggered automatically whenever the moisture content fell below the preset threshold of 30%. This ensured that the plants received the necessary amount of water without over-watering, which is a common problem in manual irrigation systems. The system proved effective in preventing water wastage while maintaining optimal plant hydration.

The Total Dissolved Solids (TDS) and Electrical Conductivity (EC) sensors, submerged in the water reservoir, successfully monitored the nutrient levels of the irrigation water. When the TDS levels dropped below 300 ppm or the EC levels fell below 700 µS/cm, the system triggered alerts, indicating that nutrients needed to be added to the water. These alerts were configured to prompt either manual or automatic nutrient addition, helping maintain the ideal nutrient concentration for plant growth.

The rain sensor functioned as intended, detecting rainfall and preventing unnecessary irrigation during precipitation. This feature proved valuable in water conservation, ensuring that the system did not activate irrigation when natural rainfall was sufficient, thus reducing water usage. The solar panel and battery backup powered the entire system with high efficiency. Even on cloudy days, the solar panel provided sufficient energy to operate the sensors, water pump, and Bluetooth module, demonstrating the system's independence from the electrical grid and its sustainability.

Finally, the Bluetooth connectivity between the system and the mobile application allowed for seamless real-time monitoring and control. Users were able to view the soil moisture, TDS, and EC readings and adjust irrigation schedules or override the system as necessary, offering a high level of convenience and user control.

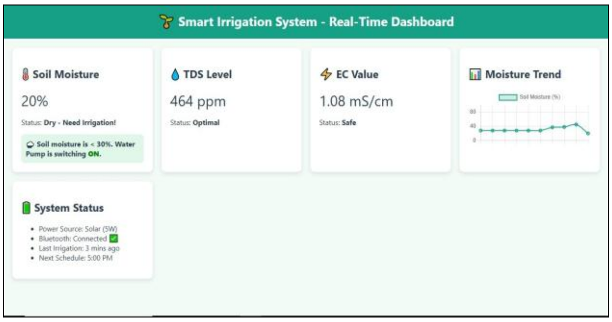

Fig 2: Soil moisture is low (20%), and the irrigation pump is automatically switched ON.

This figure (2) shows the Smart Irrigation System detecting low soil moisture at 20%, triggering the automated irrigation system. The TDS level is 464 ppm and marked as Optimal, while the EC value is 1.08 mS/cm, which falls within the Safe range. The system recognizes that moisture is below the 30% threshold and automatically switches the water pump ON. The moisture trend graph indicates a downward trend, confirming the need for irrigation.

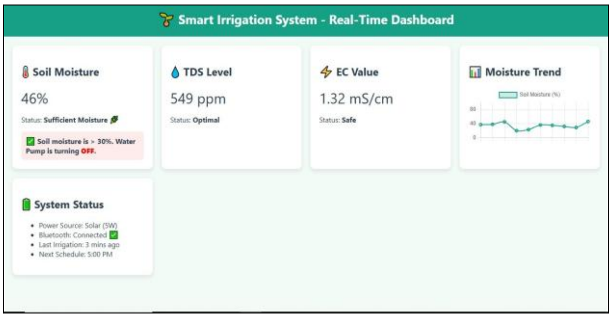

Fig 3: Soil moisture is sufficient (46%), so the irrigation pump is turned OFF.

This figure (3) shows an increased soil moisture level at 46%, indicating a well-irrigated condition. The system responds by turning OFF the water pump as the moisture has crossed the 30% threshold. The TDS reading of 549 ppm is within the Optimal range, and the EC value of 1.32 mS/cm is still Safe for general crop conditions. The moisture trend graph reflects a positive upward trend.

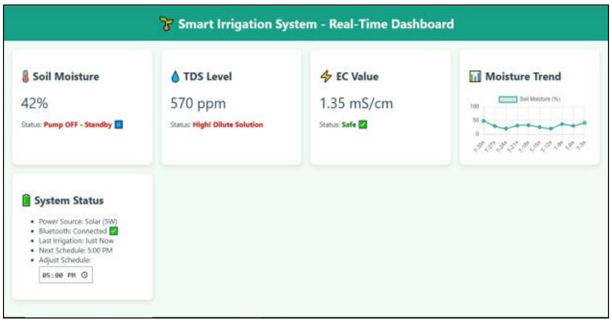

Fig 4: Soil moisture is moderate (42%), pump is on standby, and TDS is slightly high.

In figure (4) the Smart Irrigation System records a soil moisture level of 42%, which is above the irrigation threshold. The water pump remains OFF in standby mode. However, the TDS level is 570 ppm and flagged as High Dilute Solution, suggesting slightly elevated dissolved solids. The EC remains Safe at 1.35 mS/cm, and the trend graph shows stable moisture conditions post-irrigation.

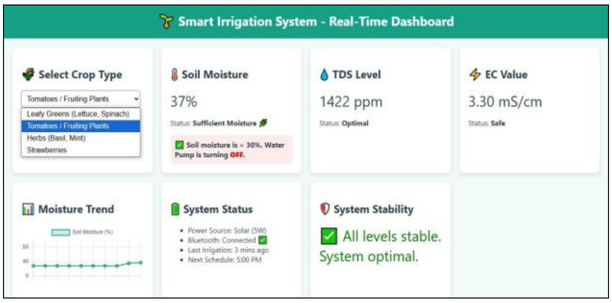

Fig 5: Crop-specific mode is enabled for tomatoes with stable conditions and optimal system performance.

In the figure (5), the dashboard highlights a crop-specific mode, with Tomatoes / Fruiting Plants selected. The soil moisture is at 37%, above the threshold, keeping the water pump OFF. The TDS level of 1422 ppm and EC value of 3.30 mS/cm fall within the Optimal and Safe ranges for tomato crops. The system confirms stability, and all parameters indicate that the system is running under optimal agricultural conditions.

Fig 6: Reference table displaying ideal EC and TDS ranges for various crop types

This figure (6), provides a reference chart listing the ideal EC (μS/cm) and TDS (ppm) ranges for common crop categories including leafy greens, tomatoes, herbs, and strawberries. This chart serves as a baseline for comparison and system calibration to ensure appropriate water and nutrient levels for different plant types.

4. Conclusion

This project successfully demonstrates the development and implementation of an IoT-based automated irrigation system tailored for rooftop gardening. By integrating soil moisture sensors, TDS/EC sensors, and a rain detector with a microcontroller and solar power system, the design offers an efficient, sustainable, and smart solution for urban agriculture. The system not only optimizes water usage and ensures appropriate nutrient delivery but also reduces manual labor and increases crop productivity. Its Bluetooth-enabled mobile application enhances user accessibility and control, making it suitable for individuals with limited time or technical expertise. The use of renewable energy further reinforces its environmental benefits and cost-effectiveness. Overall, this scalable and adaptable solution has the potential to promote self-sufficient food production in urban spaces, reduce environmental impact, and contribute meaningfully to the future of sustainable agriculture. Further improvements could include Wi-Fi integration, cloud data logging, and automated nutrient dosing to enhance its functionality and applicability in diverse urban farming scenarios.

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