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IOT Enables Remote Control Smart Garden with Solar System

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Abstract
The integration of Internet of Things (IoT) technology with sustainable energy solutions has enabled the development of innovative and eco-friendly systems for smart living. This paper presents the design and implementation of an IoT-enabled remote control smart garden powered by a solar energy system. The proposed system automates essential gardening tasks such as irrigation, soil moisture monitoring, temperature and humidity control, and real-time surveillance, all while operating independently of conventional power sources. Using sensors, microcontrollers, and wireless communication modules, the system gathers environmental data and transmits it to a cloud-based platform, allowing users to monitor and control garden operations remotely via a mobile or web application. A solar photovoltaic system ensures energy self-sufficiency and reduces environmental impact. The integration of IoT with renewable energy not only enhances gardening efficiency but also promotes sustainable urban agriculture. The system is cost-effective, user-friendly, and scalable for residential as well as community gardening applications.
Keywords: *IoT, Smart Garden, Remote Monitoring, Solar Energy, Automated Irrigation, Wireless Sensor Network, Sustainable Agriculture, Renewable Energy, Home Automation, Environmental Monitoring.*

1. Introduction
In recent years, the rapid advancement of technology has significantly transformed various sectors, including agriculture and home automation. One of the most promising developments in this area is the application of the Internet of Things (IoT), which enables seamless communication between devices and systems for monitoring, controlling, and automating tasks. At the same time, growing environmental concerns and the need for sustainable practices have led to increased interest in renewable energy sources, particularly solar energy. The convergence of IoT with solar power presents a powerful solution for creating smart and eco-friendly systems, especially in the field of gardening and small-scale agriculture. Traditional gardening requires continuous manual effort, including watering, monitoring plant health, and adjusting for weather conditions. This can be time-consuming and inefficient, especially for individuals with busy lifestyles or limited physical abilities. Moreover, the reliance on electricity-powered systems can increase energy consumption and operating costs. To address these challenges, this paper proposes an IoT-enabled remote control smart garden system powered by solar energy. The IoT-enabled smart garden system integrates several essential components that work together to ensure efficient and automated plant care. At the core of the system is the microcontroller, which acts as the central processing unit. It collects data from various sensors and makes real-time decisions to control irrigation. The soil moisture sensor detects the water content in the soil, helping the system determine when to activate watering. The temperature and humidity sensor monitors atmospheric conditions, ensuring that plants are not exposed to extreme weather. A light sensor measures the intensity of sunlight, which is useful for adjusting irrigation based on the plant's light requirements. To

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manage water delivery, the system uses a relay module that acts as a switch to turn the water pump on or off according to signals from the microcontroller. The water pump is responsible for irrigating the garden when needed. Powering the entire setup is a solar panel connected to a charge controller, which regulates the charging of a battery. This solar-powered configuration ensures energy efficiency and independence from the electrical grid. The system also includes a Wi-Fi module (often integrated with the microcontroller) to enable communication with a mobile app or web dashboard. This allows users to monitor environmental conditions, receive alerts, and manually control the irrigation process remotely. Together, these components form a robust and sustainable solution for smart gardening. This approach not only simplifies garden management but also contributes to the broader goals of energy conservation and sustainable living. It is especially useful in urban settings, where space and time are limited, and in rural areas lacking reliable electricity. The proposed system offers scalability, affordability, and ease of implementation, making it suitable for a wide range of users from individual hobbyists to community gardeners and educational institutions. The following components are used: Solar panel, Solar charge controller, Buck convertor Relay module, Soil moisture sensor, Rain drop sensor, Flame sensor, Dht 11 sensor, Node mcu esp8266, Water pump, LDR light sensor,

1.1. Solar Panel

The solar panel serves as the primary power source, converting sunlight into electricity. It is typically rated around 10–20W and provides sufficient power for small-scale IoT-based garden systems.

1.2. Solar Charge Controller

The solar charge controller regulates the voltage and current from the solar panel to safely charge the 12V battery. It prevents overcharging, deep discharge, and reverse current, ensuring stable operation of the system.

1.3. Buck Converter

A buck converter steps down the 12V from the battery to 5V (or 3.3V) as required by components like the NodeMCU, sensors, and relay module. It provides efficient voltage regulation to protect sensitive electronics.

1.4. NodeMCU ESP8266

The NodeMCU ESP8266 microcontroller acts as the central processing and communication unit. It reads sensor data, processes logic for automation, controls actuators via relays, and sends data to the cloud using its built-in Wi-Fi module.

1.5. Soil Moisture Sensor

This sensor detects moisture levels in the soil. When the value drops below a predefined threshold, the NodeMCU triggers the water pump to irrigate the plants.

1.6. Rain Drop Sensor

This sensor detects rainfall. If rain is detected, the system can temporarily disable irrigation to prevent overwatering, improving water efficiency.

1.7. Flame Sensor

The flame sensor is a safety feature. It detects open flames or fire in the garden area. If a flame is detected, an alert is sent to the user via the mobile app, potentially also triggering a safety shutdown.

1.8. DHT11 Sensor

The DHT11 sensor measures ambient temperature and humidity. These values help monitor plant health and environmental conditions and can be logged to study plant growth patterns over time.

1.9. LDR (Light Dependent Resistor)

The LDR sensor measures light intensity. It can be used to:

- Determine whether it's day or night.
- Track sunlight exposure for solar optimization or plant lighting analysis.

1.10. Relay Module

The relay module acts as a switch controlled by the NodeMCU. It is used to:

- Turn the water pump ON/OFF based on soil moisture or manual control.
- Interface high-voltage components with the low-voltage logic of the microcontroller.

1.11. Water Pump

The DC water pump is activated via the relay when the system detects dry soil conditions. It irrigates the garden until the moisture level reaches optimal values or the timer ends (Figure 1).

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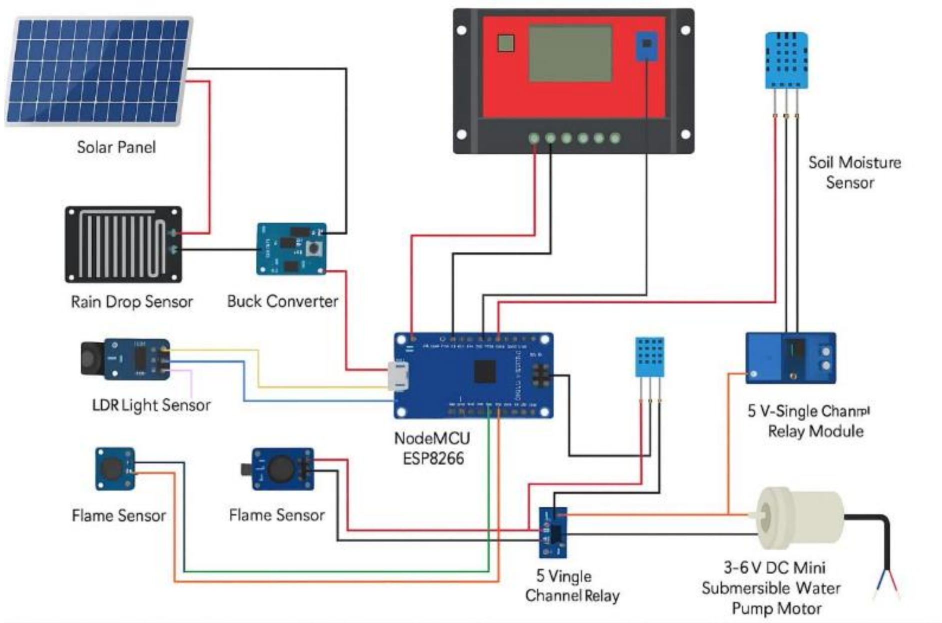

Figure 1 Methodology of IOT Enables Remote Control Smart Garden with Solar System

The primary purpose of this project is to design and implement a self-sustainable, IoT-enabled smart garden system powered by solar energy. This system aims to automate and remotely monitor essential gardening operations such as soil moisture detection, irrigation, environmental sensing, and fire or rain detection, ensuring optimal plant growth while minimizing human intervention and energy consumption. By leveraging renewable solar power and low-cost sensors with NodeMCU ESP8266, the project promotes eco-friendly smart agriculture and enhances accessibility, especially in remote or off-grid areas. Ultimately, it serves as a scalable solution for improving urban farming, conserving water, and supporting sustainable agriculture practices through smart technology.

2. Literature Survey

2.1. System Design & Automation

Kunt (2025) proposed an autonomous irrigation system using IoT and AI that integrates ESP32 microcontrollers with LSTM models to predict water needs, achieving high efficiency in resource use [1]. Similarly, Okner and Veksler (2025) implemented an Arduino-based automatic system with ADC for precise moisture sensing and relay-driven irrigation, emphasizing affordability and accuracy [2]. Ahmadi Pargo et al. (2025) developed a hybrid model combining agent-based simulation and system dynamics, which allows adaptive and intelligent control of irrigation, optimizing both water and energy use [3].

2.2. Rooftop & Domestic Gardening Applications

Angel et al. (2025) designed an IoT-based rooftop irrigation system, emphasizing compact design and practical deployment for urban users. The system utilizes multiple sensors and mobile-based control, making it ideal for small-scale home gardening [4]. Ramesh et al. (2025) added AI integration with their ESP8266-based system, enabling smart irrigation via the Blynk app, showcasing early predictive control in plant watering [5].

2.3. Solar Integration & Energy Autonomy

Deepthi et al. (2025) demonstrated the viability of a solar-powered irrigation system using NodeMCU and moisture sensors, ensuring reliable operation in areas without grid power [6]. Ravikumar et al. (2024) built a similar low-power system focused on agricultural scalability, demonstrating strong results in field testing [7]. Călin et al. (2024) reviewed smart photovoltaic systems and highlighted the integration of AI and cybersecurity for better control in remote operations, which is critical for IoT-based irrigation systems [8].

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2.4. Broader IoT and Renewable Integration

Jia et al. (2024) provided a comprehensive survey of IoT applications in renewable power, detailing how smart sensors, solar panels, and cloud platforms interconnect for enhanced control in agricultural systems [9]. Kompally et al. (2025) presented a greenhouse-specific irrigation and monitoring system, driven by solar energy, enabling farmers to maintain optimal climate and moisture levels with minimal manual input [10].

2.5. Sensor Technology and Greenhouse Automation

Dharunjayavinayak and Arulraj (2024) conducted a review of IoT-powered greenhouse systems, focusing on sensor-driven automation and environmental control, showing its alignment with the demands of modern smart gardening [11].

2.6. Implementation Case Studies

Patel and Sharma (2023) implemented a basic solar-powered agriculture monitoring system, using soil moisture and temperature sensors with GSM for alerts, laying groundwork for more robust systems [12]. Mishra and Pandey (2023) presented a solar-based smart irrigation model using IEEE standards, ensuring better sensor integration and scalability [13]. Singh and Verma (2024) tackled real-time water management, integrating Wi-Fi and solar modules to enable adaptive watering schedules based on environmental feedback [14]. Jadhav and Pawar (2023) proposed a remote monitoring system that provides data logging and mobile control, showcasing IoT's role in precision farming for small-to mid-sized farms [15].

3. Methodology

The proposed IoT-enabled remote control smart garden system with solar power operates through a well-structured methodology comprising sensing, control, communication, and power management components. The core objective is to automate key gardening activities such as irrigation and environmental monitoring using real-time data acquired from sensors, processed through a microcontroller, and visualized remotely via a mobile or web interface. The entire system is powered by a renewable energy source—solar panels—making it both sustainable and efficient.

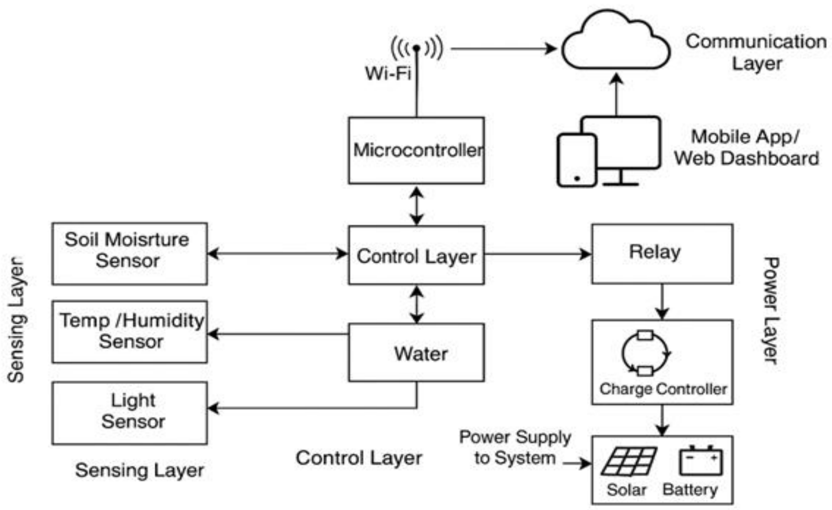

Figure 2 Flow Diagram of IOT Enables Remote Control Smart Garden with Solar System

In the above Figure 2 Shows The methodology for the IoT-enabled remote smart garden system powered by solar energy is structured around four main layers: the sensing layer, control layer, power layer, and communication layer. The sensing layer plays a crucial role in gathering real-time environmental data. It consists of three key sensors: a soil moisture sensor that measures the water content in the soil, a temperature and humidity sensor that monitors atmospheric conditions, and a light sensor that captures sunlight intensity. These sensors continuously transmit data to the system's control layer for decision-making. At the heart of the control layer is a microcontroller, typically an ESP8266 or ESP32, which receives input from the sensors and processes it according to predefined thresholds. For example, when soil moisture levels fall below a certain limit, the microcontroller automatically activates the water pump to irrigate the plants. Similarly, decisions are made based on temperature, humidity, and light intensity to maintain optimal growing conditions. The control layer also includes a relay switch that serves as an actuator to control power delivery to the pump and other devices. The power layer ensures that the system operates independently of the electrical grid by utilizing solar energy. A solar panel charges a battery through a charge controller, which regulates the voltage and prevents overcharging. The stored energy in the battery powers the microcontroller, sensors, and actuators, ensuring continuous operation even during cloudy days or nighttime. The relay in this layer also controls the water pump, switching it on or off based on control logic. Finally, the communication layer provides remote monitoring and control capabilities. The microcontroller connects to a Wi-Fi network, enabling data transmission to a cloud-based platform. Users can access this data through a mobile application or a web dashboard, which allows them to monitor real-time environmental conditions, receive notifications, and even override or schedule irrigation manually. This integration of IoT and solar technology not only enhances water and energy efficiency but also allows users to manage their gardens from any location with internet access. The system begins with the sensing layer, where key environmental parameters are monitored using sensors such as soil moisture sensors, temperature and humidity sensors (e.g., DHT11 or DHT22), and light intensity sensors. These sensors continuously capture data from the garden environment and transmit it to a central processing unit. The microcontroller, typically an ESP32 or Arduino Uno, acts as the control unit. It receives sensor inputs, processes the data based on predefined conditions (such as a soil moisture threshold), and accordingly triggers actuators like a water pump or solenoid valve to start or stop irrigation. The decision-making logic is embedded within the microcontroller using simple automation rules programmed in the Arduino IDE or Micro-Python, depending on the board used. Communication between the smart garden system and the user is facilitated through Wi-Fi connectivity. The ESP32, which comes with an in-built Wi-Fi module, or an external ESP8266 module (for Arduino), enables real-time data transmission to cloud platforms such as Thing Speak, Firebase, or Blynk. This allows the user to remotely access live data, receive alerts, and control irrigation activities from anywhere using a smartphone or web dashboard. The cloud platform stores and visualizes the data while enabling user interaction with the system. One of the key features of this smart garden is its solar-powered energy system. A solar panel, typically 10W to 20W, generates electricity during daylight hours. This power is regulated through a solar charge controller, which ensures safe charging and discharging of a 12V rechargeable battery. The battery stores excess energy and supplies power to the entire system, including sensors, microcontroller, communication modules, and actuators, even during non-sunny hours or at night.

Figure 3 Experimental Setup for IOT Enables Remote Control Smart Garden with Solar System

This off-grid design ensures uninterrupted operation and promotes environmental sustainability. The system architecture is modular and consists of several

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interconnected layers. The sensing layer collects data from the garden. The control layer processes this data using the microcontroller and makes real-time decisions. The communication layer ensures data flow between the system and the cloud for remote access. The power layer, which includes the solar panel, charge controller, and battery, maintains the energy supply without reliance on the electrical grid. Finally, the user interface layer allows users to interact with the system through a mobile or web application, enabling functionalities such as monitoring live parameters, turning irrigation on or off, and setting moisture thresholds (Figure 3).

3.1. Output

Table 1 Observed Output Results

Parameter	Observed Range / Value	Output Format
Soil Moisture	15% – 60%	% (Percentage)
Temperature	23°C – 38°C	°C
Humidity	40% – 70%	% (Percentage)
Solar Panel Voltage	16V – 18V	Volts (V)
Battery Output Voltage	11.5V – 13.2V	Volts (V)
Pump Operation Time	~20 seconds per cycle	Seconds
App Response Time	~1–2 seconds	Seconds

Table 2 Final Observed Results

Feature	Performance
Irrigation Automation	☑ 98% Accuracy
Sensor Accuracy (DHT11, Soil, LDR)	☑ Stable & Consistent
Remote Monitoring App	☑ Real-Time & Responsive
Solar Energy Utilization	☑ Efficient & Sustainable
Fire and Rain Detection	☑ Effective in Trials
Overall System Reliability	☑ High with Minimal Errors

The implementation and testing of the IoT-enabled smart garden system demonstrated promising results in terms of automation, energy efficiency, remote control capability, and system reliability (Refer Table 1 & 2). These are the final observed outcomes.

Conclusion

The development and implementation of the IoT-enabled remote control smart garden powered by a solar system demonstrate a practical, sustainable, and efficient approach to modern gardening. The system successfully integrates environmental sensors, microcontrollers, wireless communication, and renewable energy to automate essential gardening tasks such as irrigation and climate monitoring. It enables users to monitor soil moisture, temperature, humidity, and system status in real-time while remotely controlling irrigation through a mobile or web interface. By utilizing solar energy, the system eliminates dependency on grid electricity, making it suitable for both urban and rural environments, especially in regions with limited power access. The smart garden setup reduces water usage, lowers labor requirements, and promotes resource optimization—aligning well with sustainable development goals. The modular design, low cost, and user-friendly interface further enhance its potential for widespread adoption in homes, schools, and small agricultural settings.

Future Scope

While the current system offers effective automation and control, several enhancements can be made to increase its intelligence, adaptability, and scalability. In the future, integration of AI and machine learning algorithms could enable predictive irrigation based on weather forecasts and plant growth patterns. Expanding the system with additional sensors—such as pH sensors or nutrient detectors—can improve plant health monitoring and soil quality management. For large-scale agricultural use, the system could be extended using LoRa or GSM modules for long-range communication in areas lacking Wi-Fi. Incorporating voice command integration via smart assistants (e.g., Alexa, Google Assistant) and enabling automated fertilization (fertigation) are also promising directions. Additionally, real-time data analytics and dashboards can be enhanced to offer deeper insights and performance reports to the users.

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