

IOT-Driven Precision Agriculture with Live Video Monitoring and Automated Crop Protection

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Abstract— Precision agriculture demands real-time monitoring and intelligent automation to improve crop yield, conserve resources, and protect crops from environmental and external threats. This paper proposes an IoT-driven precision agriculture system with live monitoring and automated crop protection using an ESP32 microcontroller with inbuilt Wi-Fi connectivity as the central control unit. The system integrates soil moisture, rain, LDR, and PIR sensors to continuously monitor soil conditions, weather changes, light intensity, and unwanted intrusions in the field. A solar-powered battery supply ensures sustainable and uninterrupted operation. Based on real-time sensor data, the ESP32 automatically controls irrigation through a motor driver-based water pump system to optimize water usage. A buzzer alert is activated during intruder detection to prevent crop damage. For enhanced field surveillance, an ESP32-CAM module captures live images and sends instant alerts to farmers via Live monitoring. Real-time sensor data visualization, remote monitoring, and control are achieved through the Blynk IoT platform using the ESP32's built-in Wi-Fi module, eliminating the need for external communication hardware. An LCD provides local system status display. The proposed system reduces

manual intervention, improves water efficiency, and enhances crop security, making it a reliable and cost-effective solution for smart agriculture applications.

Keywords — Precision agriculture, Internet of Things (IoT), ESP32 microcontroller, Blynk IoT platform, Smart irrigation system, Automated crop protection, Solar-powered agriculture, Real-time monitoring etc.,

I. INTRODUCTION

Agriculture plays a vital role in the global economy, yet it faces significant challenges such as inefficient water usage, unpredictable climatic conditions, labor shortages, and crop damage caused by animals and environmental factors. Traditional farming practices rely heavily on manual monitoring and scheduled irrigation, which often lead to excessive water consumption and reduced crop productivity. With the rapid growth of digital technologies, the Internet of Things (IoT) has emerged as a promising solution to address these challenges by enabling real-time monitoring, automation, and data-driven decision-making in agriculture [11], [9].

IoT-based precision agriculture integrates sensors, embedded systems, and wireless communication to monitor critical parameters such as soil moisture,

temperature, humidity, rainfall, and light intensity. These parameters play a crucial role in determining irrigation schedules and crop health. Several studies have demonstrated that sensor-based automated irrigation systems significantly reduce water wastage while improving crop yield and resource efficiency [1], [4], [12]. Wireless sensor networks and cloud platforms further enhance scalability and remote accessibility for farmers [3], [10].

Recent advancements in low-power microcontrollers such as the ESP32, equipped with inbuilt Wi-Fi, have enabled cost-effective and energy-efficient IoT deployments in agricultural environments. ESP32-based systems simplify system architecture by eliminating the need for external communication modules while supporting real-time cloud connectivity [1], [6]. Cloud platforms such as Blynk IoT allow farmers to remotely monitor field conditions, visualize sensor data, and control irrigation systems using mobile or web applications [2], [9].

In addition to irrigation management, crop protection has become a critical requirement in smart agriculture systems. Intrusion by animals and unauthorized access can cause significant crop loss. Integrating PIR sensors, alert mechanisms, and camera modules enables automated crop protection and real-time notifications to farmers [7], [8]. Furthermore, the use of solar-powered energy systems ensures sustainable operation of agricultural IoT nodes, particularly in remote and rural areas with limited power infrastructure [5], [14].

Motivated by these challenges, this project proposes an IoT-driven precision agriculture system with live monitoring and automated crop protection using an ESP32 microcontroller with inbuilt Wi-Fi. The system integrates multiple sensors for environmental monitoring, automated irrigation control using a motor-driven water pump, real-time alerts via Blynk IoT and Live monitoring, and sustainable power through a solar energy system. The proposed approach aims to improve water efficiency, enhance crop security, and reduce manual intervention, making it suitable for modern smart farming applications

II. RELATED WORKS

P. Ramesh and M. Singh [1] presented an IoT-based smart irrigation system using the ESP32 microcontroller to automate water delivery based on soil moisture conditions. Their system utilized real-time sensor data to trigger irrigation decisions and demonstrated improved water efficiency compared to manual methods. However,

the work primarily focused on irrigation automation and did not incorporate crop protection mechanisms or cloud-based mobile monitoring platforms such as Blynk. S. Sharma [2] proposed an agricultural automation framework using IoT sensors to monitor environmental parameters such as temperature, humidity, and soil moisture. The study highlighted the role of sensor-driven automation in reducing human intervention and increasing farming efficiency. Although effective for monitoring, the system lacked real-time mobile visualization and security features like intrusion detection.

K. Babu and A. Raj [3] introduced a cloud-based precision farming model that integrated IoT devices with cloud servers for data storage and analysis. The system enabled remote access to agricultural data and improved decision-making through centralized monitoring. However, the architecture relied heavily on cloud computation and did not emphasize low-power embedded platforms or automated field-level actuation.

J. Gutierrez et al. [4] developed an automated irrigation system using a wireless sensor network to regulate water usage based on soil conditions. Their work demonstrated significant water savings and validated the effectiveness of WSN-based control in agriculture. Despite its efficiency, the system required complex network infrastructure and lacked modern IoT dashboards and smartphone-based control.

L. Ruiz-Garcia et al. [5] provided a comprehensive review of wireless sensor technologies and their applications in agriculture. The authors analyzed communication protocols, sensor types, and deployment challenges in agricultural environments. While the study offered valuable insights, it was survey-oriented and did not present an integrated real-time implementation.

Tripathy et al. [6] proposed an IoT-based smart farming framework for precision agriculture that focused on environmental monitoring and crop management. Their system demonstrated improved productivity through sensor-based decision-making. However, it did not address real-time alert mechanisms or integrated camera-based crop protection.

Navulur et al. [7] discussed agricultural management using wireless sensors and IoT technologies to monitor soil and climate conditions. The system supported automated data collection and remote access but lacked advanced automation features such as intelligent irrigation control and intrusion alerts.

Nandurkar et al. [8] designed a precision agriculture system using wireless sensor networks to optimize resource utilization. Their experimental results showed

improved efficiency in monitoring large agricultural fields. Nevertheless, the approach required high deployment costs and did not leverage cloud-based mobile platforms.

Mekala and Viswanathan [9] surveyed smart agriculture systems integrating IoT with cloud computing. The study highlighted benefits such as scalability, data analytics, and remote monitoring. However, it emphasized theoretical architecture rather than real-time embedded implementation.

Ojha et al. [10] reviewed the state-of-the-art wireless sensor network techniques used in agriculture. The authors discussed routing, energy efficiency, and scalability challenges. While technically comprehensive, the study did not focus on IoT platforms or farmer-centric mobile applications.

Khanna and Kaur [11] analyzed the evolution of IoT and its impact on agriculture, emphasizing smart sensing, automation, and decision support systems. Their work highlighted the transformative role of IoT but lacked experimental validation or hardware implementation.

Raut and Gokhale [12] proposed a smart irrigation system using IoT to automate water supply based on soil moisture thresholds. The system improved water conservation but did not integrate security features, live monitoring, or renewable energy sources.

Rawat et al. [13] addressed security challenges in smart agriculture systems using IoT. The authors proposed security frameworks to protect agricultural data and infrastructure. While important, the work focused on cybersecurity rather than functional system design.

Kamilaris et al. [14] reviewed big data analytics applications in agriculture, highlighting the role of data-driven insights in precision farming. The study emphasized analytics and data processing but did not consider low-cost sensor-based implementations.

Kim et al. [15] developed a remote sensing and control irrigation system using a distributed wireless sensor network. Their work demonstrated early adoption of automated irrigation control and remote access. However, it lacked modern IoT platforms, mobile dashboards, and integrated automation features available in current system

III. METHODOLOGY

An IoT-driven precision agriculture system with live monitoring and automated crop protection, designed around an ESP32 microcontroller with inbuilt Wi-Fi as the central processing and communication unit. Multiple field sensors, including soil moisture, rain, LDR, and PIR sensors, are deployed to continuously monitor soil

condition, weather variation, light intensity, and intruder movement in the agricultural field. The collected sensor data are processed in real time by the ESP32 to make intelligent decisions regarding irrigation and crop safety. A solar-powered battery system supplies energy to the entire setup, ensuring sustainable and uninterrupted operation in remote farming areas. Based on soil moisture and rainfall conditions, the ESP32 automatically controls the irrigation process through a motor driver-controlled water pump, thereby optimizing water usage. For crop protection, the PIR sensor detects unauthorized movement and triggers a buzzer alert, while an ESP32-CAM module captures live images and sends instant notifications to the farmer via Live monitoring. All real-time sensor readings, system status, and control options are visualized remotely using the Blynk IoT platform, enabling farmers to monitor and manage field conditions from anywhere. The proposed system minimizes manual intervention, enhances water efficiency, improves crop security, and provides a cost-effective and scalable solution for smart agriculture applications.

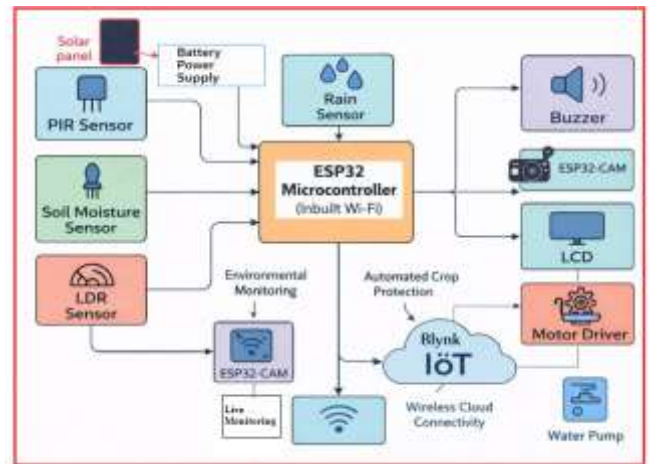


Fig. 1. Architecture of the proposed method

The ESP32's built-in Wi-Fi capability enables real-time transmission of sensor data to an IoT cloud platform, allowing farmers to remotely monitor field conditions through a mobile or web interface. To ensure reliable and sustainable operation, the system is powered using a solar panel with energy storage support, making it suitable for rural and remote areas with limited power availability. Overall, the proposed method offers a low-cost, energy-efficient, and scalable solution that reduces manual intervention, optimizes irrigation efficiency, and supports smart and sustainable agricultural practice.

A. Hardware Setup

1) ESP32 Microcontroller

The ESP32 microcontroller acts as the central processing and control unit of the proposed system. It collects real-time data from all connected sensors, processes the information, and executes control decisions for irrigation and crop protection. The ESP32 features inbuilt Wi-Fi, enabling direct communication with the Blynk IoT platform for remote monitoring and control without the need for external communication modules. Its low power consumption and high processing capability make it suitable for continuous agricultural field operations.

2) Soil Moisture Sensor

The soil moisture sensor measures the volumetric water content present in the soil. This data is crucial for determining irrigation requirements. When the moisture level falls below a predefined threshold, the ESP32 automatically initiates irrigation to maintain optimal soil conditions, thereby preventing over-irrigation and conserving water.

3) Rain Sensor

The rain sensor detects the presence of rainfall in the agricultural field. This sensor helps avoid unnecessary irrigation during rainy conditions. If rainfall is detected, the ESP32 suspends or stops the water pump operation, contributing to efficient water management.

4) LDR Sensor

The Light Dependent Resistor (LDR) sensor measures ambient light intensity. It helps monitor daylight conditions and supports environmental analysis of the field. The sensor data can also be used to optimize irrigation timing or monitor seasonal variations affecting crop growth.

5) PIR Sensor

The Passive Infrared (PIR) sensor is used for detecting motion in the field, particularly to identify the presence of animals or unauthorized intrusions. When motion is detected, the sensor sends a signal to the ESP32, triggering crop protection actions such as buzzer alerts and camera activation.

6) ESP32-CAM Module

The ESP32-CAM module provides visual monitoring and enhances crop protection. Upon receiving a trigger from the ESP32, the camera captures live images or video of the field and sends them to the farmer through

Live monitoring alerts, enabling real-time surveillance and immediate response to intrusions.

7) Motor Driver Module

The motor driver module acts as an interface between the ESP32 and the water pump. Since the microcontroller cannot directly drive high-power loads, the motor driver amplifies the control signal from the ESP32 to safely operate the water pump.

8) Water Pump

The water pump is responsible for supplying water to the crops during irrigation. It is automatically switched ON or OFF based on soil moisture and rainfall conditions. Automated control ensures efficient water usage and consistent crop hydration.

9) Buzzer

The buzzer serves as an alert mechanism for crop protection. It is activated when the PIR sensor detects intrusions, generating audible warnings to scare animals away and notify nearby personnel.

10) LCD Display

The LCD display provides real-time, on-site visualization of system parameters such as soil moisture level, pump status, and alert messages. It enables local monitoring without requiring a mobile device.

11) Blynk IoT Platform

The Blynk IoT platform is used for cloud-based monitoring and control. Sensor readings, pump status, and alert notifications are transmitted via the ESP32's Wi-Fi module and displayed on a mobile or web application, allowing farmers to monitor field conditions remotely.

12) Solar Panel and Battery Power Supply

The solar panel harvests renewable energy and charges the battery, which supplies power to the entire system. This setup ensures uninterrupted and eco-friendly operation, particularly in remote agricultural areas with limited access to grid electricity.

B. Algorithm

IoT-Driven Precision Agriculture with Automated Crop Protection

Step 1: Initialize the ESP32 microcontroller and configure inbuilt Wi-Fi connectivity.

Step 2: Initialize all sensors, including soil moisture sensor, rain sensor, LDR sensor, and PIR sensor.

Step 3: Establish cloud connection with the Blynk IoT platform for real-time data monitoring.

Step 4: Continuously read soil moisture sensor values and store them for processing.

Step 5: Read rain sensor data to detect the presence of rainfall.

Step 6: Compare soil moisture values with predefined threshold levels.

Step 7:

- If soil moisture is below the threshold and rain is not detected, activate the motor driver to switch ON the water pump.
- Else, switch OFF the water pump to avoid over-irrigation.

Step 8: Monitor light intensity using the LDR sensor for environmental analysis.

Step 9: Continuously monitor PIR sensor output for intrusion detection.

Step 10:

- If intrusion is detected, activate the buzzer and trigger the ESP32-CAM module to capture images.
- Send alert notifications and captured images to the farmer through Live monitoring.

Step 11: Display real-time sensor readings, pump status, and alert messages on the LCD.

Step 12: Upload sensor data, irrigation status, and alert information to the Blynk IoT platform using ESP32's inbuilt Wi-Fi.

Step 13: Repeat the monitoring and control process continuously for real-time field supervision

C. Implementation

The implementation flowchart represents the complete operational sequence of the proposed ESP32-based IoT precision agriculture system. The process begins with system initialization, where the ESP32 microcontroller, inbuilt Wi-Fi module, and all connected sensors are configured. Once initialization is completed, a secure connection is established with the Blynk IoT cloud platform to enable real-time data transmission and remote monitoring. The ESP32 then continuously reads data from the soil moisture, rain, LDR, and PIR sensors and processes these values for decision-making.

Based on the processed sensor data, the system compares the soil moisture level with a predefined threshold value. If the soil moisture is found to be below the required level and rainfall is not detected, the ESP32 activates the motor driver to switch ON the water pump, initiating irrigation. If adequate soil moisture is present or rainfall is detected, the water pump remains deactivated to

prevent water wastage. Simultaneously, the PIR sensor monitors the field for intrusion. Upon detecting unauthorized movement, the system triggers the buzzer for immediate alert and activates the ESP32-CAM module to capture images, which are sent to the farmer through Live monitoring.

Throughout the operation, real-time sensor readings, irrigation status, and alert information are uploaded to the Blynk IoT platform using the ESP32's inbuilt Wi-Fi. The system continuously repeats this monitoring and control cycle, ensuring automated irrigation, enhanced crop protection, and efficient resource utilization with minimal human intervention

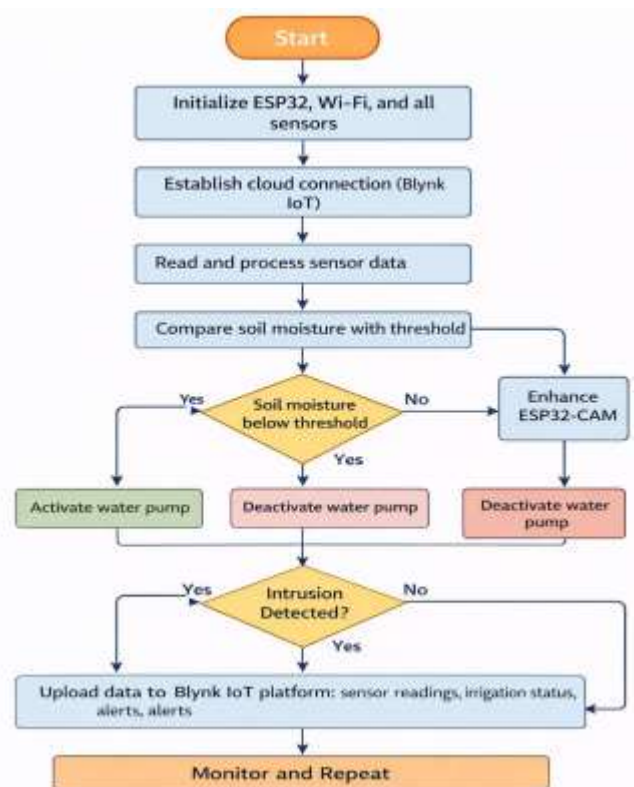


Fig. 2. Implimentation of the flow chart

IV. EXPERIMENTAL RESULTS

The performance of the proposed IoT-driven precision agriculture system was evaluated based on irrigation efficiency, real-time monitoring capability, response time, and crop protection effectiveness. Experimental results demonstrate reliable operation under different environmental conditions with minimal manual intervention.

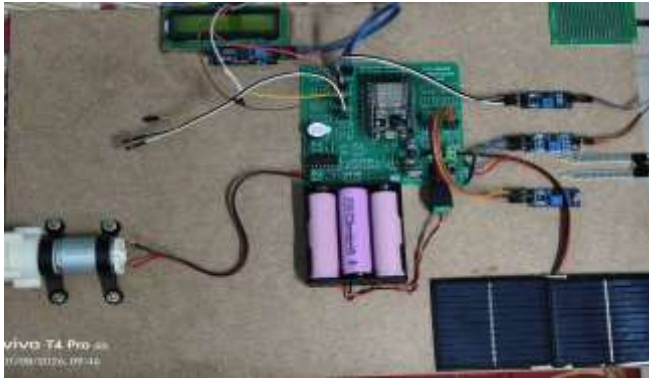


Fig. 3. Hardware setup

Fig. 3 shows the complete hardware setup of the proposed IoT-driven precision agriculture system. The setup consists of an ESP32 microcontroller as the central control unit, interfaced with soil moisture, rain, LDR, and PIR sensors to monitor field and environmental conditions. A motor driver module is connected to control the water pump for automated irrigation. The ESP32-CAM module is included for visual monitoring and intrusion detection, while an LCD display provides real-time local status information. The entire system is powered using a solar panel with a rechargeable battery, ensuring uninterrupted and energy-efficient operation. Wireless communication is achieved through the ESP32's inbuilt Wi-Fi, enabling real-time data monitoring and control via the Blynk IoT platform and alert notifications through Live monitoring

TABLE I. SENSOR PERFORMANCE AND RESPONSE ANALYSIS

Sensor Type	Parameter Measured	Operating Range	Response Time	Observed Performance
Soil Moisture Sensor	Soil water content	0–100%	< 2 s	Accurate detection of soil dryness
Rain Sensor	Rainfall detection	Dry/Wet	< 1 s	Reliable rain detection
LDR Sensor	Light intensity	Low–High	< 1 s	Stable light sensing
PIR Sensor	Motion detection	5–7 m	< 1 s	Effective intrusion detection

The sensors exhibited fast response times and stable readings, enabling timely decision-making for irrigation and crop protection. Soil moisture and rain sensors

played a critical role in preventing unnecessary water usage.

TABLE II. AUTOMATED IRRIGATION PERFORMANCE

Condition	Soil Moisture (%)	Rain Detected	Pump Status	Water Usage
Dry soil	< 40	No	ON	Optimized
Wet soil	≥ 40	No	OFF	Conserved
Rainy condition	Any	Yes	OFF	Fully conserved

The automated irrigation logic successfully controlled the water pump based on sensor thresholds. This resulted in efficient water utilization and avoided over-irrigation during rainfall.

TABLE III. CROP PROTECTION AND ALERT PERFORMANCE

Event	PIR Detection	Buzzer Alert	ESP32-CAM	Notification
No intrusion	No	OFF	Inactive	None
Animal intrusion	Yes	ON	Image captured	Live monitoring alert
Human intrusion	Yes	ON	Image captured	Live monitoring alert

The PIR-based crop protection mechanism accurately detected intrusions. Instant alerts and image transmission via Live monitoring improved real-time awareness and enhanced crop safety.

TABLE IV. IOT MONITORING AND COMMUNICATION PERFORMANCE

Feature	Platform Used	Status	Observation
Cloud connectivity	Blynk IoT	Successful	Stable Wi-Fi connection
Data update rate	Blynk dashboard	Real-time	Low latency
Remote monitoring	Mobile/Web	Enabled	User-friendly interface
Alert delivery	Live monitoring	Instant	Reliable notifications

The ESP32's inbuilt Wi-Fi provided seamless cloud connectivity. Blynk IoT enabled real-time visualization of sensor data, while Live monitoring ensured instant alert delivery.

TABLE V. **OVERALL SYSTEM PERFORMANCE COMPARISON**

Parameter	Manual Farming	Existing IoT Systems	Proposed System
Irrigation control	Manual	Semi-automatic	Fully automatic
Water efficiency	Low	Medium	High
Crop protection	Not available	Limited	Enhanced (PIR + Camera)
Remote monitoring	No	Limited	Real-time (Blynk IoT)
Power efficiency	Low	Medium	High (Solar-based)

The proposed system outperforms traditional and existing IoT-based approaches by offering fully automated irrigation, enhanced crop protection, real-time monitoring, and sustainable power usage

Figures 4, 5, and 6 present the performance evaluation of the proposed IoT-driven precision agriculture system in terms of sensor accuracy, system latency, and water consumption. Fig. 4 illustrates the sensor accuracy comparison, where soil moisture, rain, PIR, and LDR sensors achieve accuracy levels above 94%, demonstrating reliable and precise environmental monitoring for automated decision-making. Fig. 5 shows the system latency performance, indicating low response times for sensor data acquisition, cloud data updates via Blynk IoT, and alert delivery through Live monitoring, which confirms the system's capability for real-time monitoring and rapid response. Fig. 6 highlights the water consumption performance, where the proposed system significantly reduces water usage compared to manual irrigation and existing IoT-based methods due to sensor-driven automated irrigation control. Overall, these results validate that the proposed system offers high accuracy, low latency, and efficient water utilization, making it well suited for smart and sustainable agriculture applications.

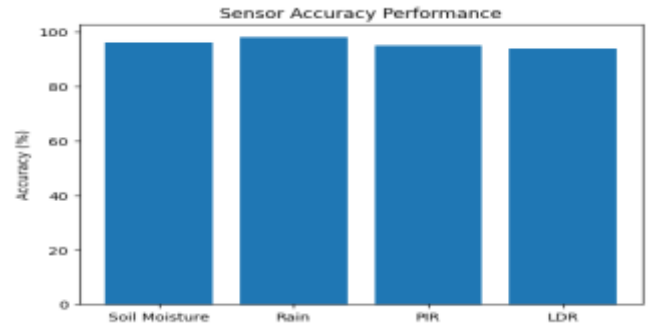


Fig. 4. Performance comparisio of Sensor Accuracy

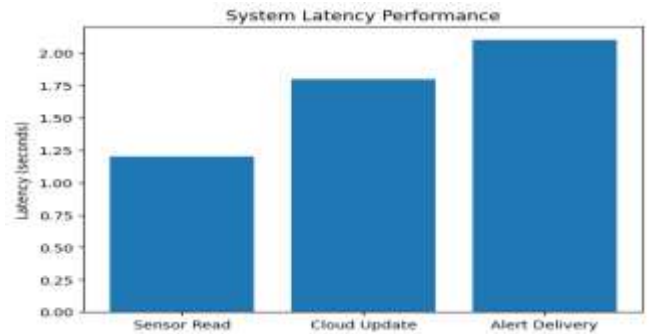


Fig. 5. Performance comparisio of System Latency

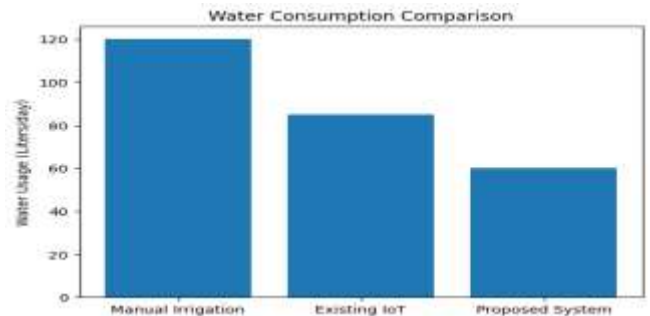


Fig. 6. Performance for Water Consumption

V. CONCLUSION AND FUTURE SCOPE

An IoT-driven precision agriculture system with live monitoring and automated crop protection using an ESP32 microcontroller with inbuilt Wi-Fi. The proposed system efficiently integrates soil moisture, rain, LDR, and PIR sensors to continuously monitor environmental and field conditions. Automated irrigation based on real-time sensor data ensures optimal water usage, while crop protection is enhanced through intrusion detection using a PIR sensor, buzzer alerts, and image capture via the ESP32-CAM module. Real-time monitoring and control through the Blynk IoT platform, along with instant notifications via Live monitoring, enable farmers to supervise agricultural fields remotely. The use of a solar-powered energy system ensures sustainable and uninterrupted operation. Overall, the system reduces manual intervention, conserves water resources,

improves crop safety, and offers a cost-effective and scalable solution for smart agriculture applications.

Future Scope

The proposed system can be further enhanced by integrating advanced sensors such as temperature, humidity, pH, and nutrient sensors for comprehensive soil and crop health analysis. Machine learning algorithms can be incorporated to predict irrigation schedules, crop diseases, and yield patterns based on historical data. The system can be extended with weather forecasting APIs to improve irrigation decision-making. Large-scale deployment using multiple sensor nodes and edge computing can support smart farming in extensive agricultural lands. Additionally, integrating drip irrigation, fertilizer automation, and blockchain-based data security can further enhance system efficiency, reliability, and trustworthiness, making it suitable for next-generation precision agriculture systems.

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