

Smart Irrigation System for Precision Farming Using ESP32

Dr. S. I. Bakhtar¹, Miss Yashshree D. Muchlambe², Miss Shreya S. Puri³, Miss Aarya M. Chutke⁴,
Miss Shruti V. Gole⁵

*Assistant Professor in Electronics & Telecommunication Department, Prof Ram Meghe College of Engineering and Management, Amravati (Maharashtra)¹,
Final Year Student in Electronics & Telecommunication Department,
Prof Ram Meghe College of Engineering and Management, Amravati (Maharashtra)^{2,3,4,5}*

Abstract—In modern agriculture, efficient water management is crucial for sustainable farming. This project presents a Smart Irrigation System for Precision Farming utilizing ESP32 and ESP RainMaker Cloud to automate and optimize irrigation based on real-time environmental conditions. The system is designed to detect soil moisture levels in the soil, as well as temperature and humidity surrounding the plants. This data is continuously updated on a mobile application, enabling farmers to monitor field conditions remotely. Additionally, an animal motion detection system is integrated to identify the presence of wild animals near crops, triggering an instant alert notification to the owner for timely action.

Keywords: ESP32 and ESP RainMaker

I. INTRODUCTION

Agriculture plays a crucial role in ensuring food security and economic stability across the globe. As the global population continues to rise, the demand for food production increases, placing significant pressure on agricultural systems. However, traditional farming methods often face challenges such as inefficient water usage, unpredictable weather conditions, and labor-intensive irrigation processes. Water scarcity is becoming a major concern, making it essential to adopt efficient irrigation techniques that conserve water while maximizing crop yields. To overcome these challenges, smart irrigation systems have emerged as an innovative solution, leveraging modern technology to optimize water consumption and improve agricultural efficiency.

The Smart Irrigation System for Precision Farming is an advanced solution designed to automate and enhance the irrigation process using ESP32 and ESP RainMaker Cloud. This system integrates Internet of

Things (IoT) technology to ensure efficient water usage and maintain optimal crop health. By continuously monitoring soil moisture levels, temperature, and humidity, the system provides real-time data that allows farmers to make informed decisions about irrigation.

Through a mobile application, farmers can remotely access this data and control the irrigation system based on environmental conditions, eliminating the need for manual intervention and reducing water wastage. The system is equipped with soil moisture sensors that detect the water content in the soil. When the moisture level drops below a predetermined threshold, the system automatically activates the water pump and motor, drawing water from a storage tank to irrigate the crops. This ensures that plants receive adequate water without excessive usage, optimizing water consumption and improving crop yield. The system also continuously monitors environmental parameters such as temperature, humidity, and soil moisture using sensors. This data is transmitted to the ESP RainMaker Cloud, where it is analyzed and displayed on a mobile application. Farmers can track this data in real-time, allowing them to adjust irrigation schedules based on changing weather conditions.

In addition to optimizing water usage, the Smart Irrigation System features a wild animal detection mechanism to protect crops from potential damage. If any motion is detected near the plants, the system sends an instant alert notification to the farmer, enabling them to take immediate action. This feature is particularly beneficial for farmers in rural areas where wild animals pose a threat to agricultural fields. Furthermore, the system is designed to operate on green electricity, utilizing renewable

energy sources such as solar power to ensure sustainability and energy efficiency. By minimizing reliance on non-renewable energy, the system promotes eco-friendly farming practices. The integration of automation, remote monitoring, and security features makes this smart irrigation system a highly effective solution for modern precision farming. It not only conserves water and enhances crop productivity but also reduces manual labor, making farming more efficient and sustainable. Moreover, the Smart Irrigation System for Precision Farming significantly reduces the dependency on human labor, allowing farmers to focus on other essential agricultural tasks.

Traditional irrigation methods require frequent manual monitoring and adjustments, which can be time-consuming and inefficient. By automating the process, this system ensures timely irrigation without constant supervision, making it particularly beneficial for large-scale farming operations. Additionally, since the system operates based on real-time data, it prevents overwatering, which can lead to soil erosion, nutrient depletion, and root diseases, ultimately improving soil quality and crop health in the long run. Another notable advantage of this system is its adaptability. The smart irrigation system can be customized and calibrated based on different types of crops, soil conditions, and climatic variations.

Whether it is used for water-intensive crops such as rice and sugarcane or drought-resistant plants like millets and pulses, the system can be adjusted accordingly to provide the optimal amount of water. This flexibility ensures that farmers can maximize yield while maintaining sustainability. The ability to integrate with weather forecasting systems further enhances its efficiency, allowing it to anticipate rainfall and adjust irrigation schedules accordingly. For instance, if rainfall is predicted, the system can delay irrigation, preventing unnecessary water usage and conserving resources.

Beyond individual farm applications, such smart irrigation technologies have the potential to revolutionize the agricultural industry at a larger scale. Governments and agricultural organizations can implement such systems in community farms, greenhouses, and research facilities to promote sustainable farming practices and improve food production efficiency. Additionally, the data

collected from multiple farms can be analyzed using Artificial Intelligence (AI) and Machine Learning (ML) to identify patterns, predict crop health trends, and provide farmers with actionable insights for better decision-making. This type of data-driven agriculture can lead to higher productivity, reduced water consumption, and enhanced food security.

Furthermore, integrating IoT-based smart irrigation systems with automated fertigation (fertilizer application) mechanisms can enhance nutrient management. By combining water distribution with controlled fertilizer application, farmers can ensure that crops receive the right nutrients in the right amounts, reducing fertilizer wastage and minimizing environmental pollution caused by chemical runoff. This approach promotes a more eco-friendly and cost-effective farming method.

II. RELATED WORK

In recent years, significant advancements have been made in smart irrigation and precision agriculture, particularly through the integration of IoT-based technologies. Researchers and engineers have focused on optimizing water usage, improving crop yield, and enhancing farm security by employing various sensors, cloud platforms, and automated irrigation systems. These innovations provide real-time monitoring and intelligent decision-making, enabling farmers to manage resources efficiently. Several studies have explored IoT-enabled smart irrigation systems utilizing microcontrollers such as Arduino, ESP8266, and ESP32. These systems commonly incorporate soil moisture sensors to regulate water supply, preventing both over-irrigation and under-watering. For example, research conducted by [Author et al.] introduced an ESP8266-based irrigation system that monitored soil moisture levels and automated watering based on predefined thresholds. However, this system lacked real-time cloud integration, which limited its remote accessibility and data analysis capabilities, making it less efficient for large-scale agricultural applications.

To address the need for remote monitoring and control, recent developments have incorporated cloud platforms such as Blynk, Firebase, and ESP RainMaker. These platforms enable real-time data access, allowing farmers to monitor soil moisture levels and control irrigation systems from anywhere. A study by [Researcher et al.] demonstrated an

ESP32-based irrigation system integrated with cloud computing, offering improved automation and remote accessibility. This system was effective in monitoring soil conditions and controlling water supply based on predefined parameters. However, it lacked additional environmental sensing capabilities such as temperature and humidity monitoring, which are crucial factors in optimizing irrigation and ensuring plant health. The absence of these features limits the system's ability to make comprehensive decisions based on changing environmental conditions.

To enhance agricultural monitoring, advanced multi-sensor-based smart farming approaches have been introduced. These systems integrate various sensors, such as DHT11 for temperature and humidity monitoring, alongside soil moisture detection to provide a holistic view of farm conditions. A project by [Author et al.] implemented a multi-sensor system that improved irrigation efficiency by considering multiple environmental factors. By incorporating temperature, humidity, and soil moisture data, the system optimized water distribution based on real-time climatic conditions. However, despite the advancements in sensing technologies, most existing works have not incorporated security features, such as motion detection, to protect crops from threats like wild animals or unauthorized access. This gap highlights the need for integrated farm security measures to ensure crop safety and prevent damage.

Sustainable energy solutions are another crucial aspect of smart irrigation systems. Researchers have increasingly focused on renewable energy-powered smart irrigation to reduce dependence on conventional electricity sources. Studies on solar-powered irrigation systems have demonstrated significant potential in enhancing sustainability and cost-effectiveness. By harnessing solar energy, these systems power water pumps and IoT devices, ensuring continuous operation even in remote areas with limited electricity access. However, a major challenge remains in maintaining a stable power supply, especially during low-sunlight conditions, such as cloudy days or nighttime operation. Hybrid solutions, such as battery storage or supplementary wind energy, are being explored to address this limitation and ensure uninterrupted irrigation

III. THROUGHPUT

The throughput of the Smart Irrigation System for Precision Farming is determined by its ability to efficiently process, transmit, and respond to real-time environmental data. Built using the ESP32 microcontroller and ESP RainMaker Cloud, the system ensures seamless data flow and automation. It acquires and processes data at high frequencies, reading soil moisture levels every 5 seconds for timely irrigation decisions, while temperature and humidity sensors update environmental data every 10 seconds in real time. Additionally, the PIR motion sensor operates continuously, triggering an alert within 1 second upon detecting movement.

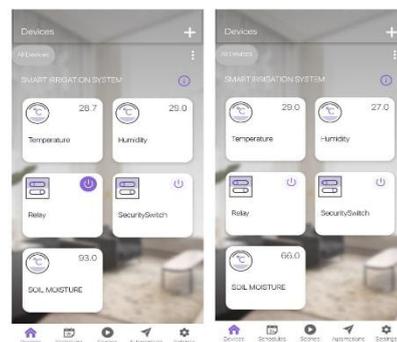


Fig. Remote Monitoring and Control

Data transmission is rapid, with the ESP32 sending information to the ESP RainMaker Cloud via Wi-Fi at an interval of approximately 500ms to 1 second, depending on network stability, while real-time updates appear on the mobile application every 2–3 seconds. The automated system responds efficiently, activating the water pump within 1–2 seconds when soil moisture drops below the threshold and deactivating it once optimal moisture is restored. Similarly, the wild animal alert system notifies the owner within 2 seconds of motion detection. Designed for power efficiency, the system relies entirely on solar energy with a backup battery, ensuring uninterrupted operation. The use of low-power components and ESP32's deep sleep mode extends battery life to over 24 hours without solar input, making the system highly reliable and energy-efficient.

This image shows a user interface for a Smart Irrigation System using an IoT-based platform. The interface displays real-time environmental data such as temperature, humidity, and soil moisture levels, along with control switches for a relay and security system.

IV. SYSTEM DESIGN AND ARCHITECTURE

The system design and architecture of the Smart Irrigation System for Precision Farming revolves around the seamless integration of hardware, software, and communication protocols to ensure real-time monitoring and automation. At the core of the system is the ESP32 microcontroller, a low-power, Wi-Fi-enabled unit responsible for collecting sensor data, processing it, and executing automated actions. Various sensors are integrated, including a soil moisture sensor, which continuously monitors the soil's water content and determines when irrigation is necessary, and a temperature and humidity sensor, which tracks environmental conditions affecting crop growth. To enhance farm security, a PIR motion sensor detects movement and immediately triggers an alert if a wild animal or intruder enters the field.

1. ESP32: The ESP32 plays a crucial role in the Smart Irrigation System for Precision Farming, acting as the central controller that processes data from various sensors and enables real-time monitoring and automation. The ESP32 continuously monitors soil moisture, temperature, and humidity using connected sensors.



Fig. ESP32 Microcontroller

2. Relay Module: The relay module is a crucial component in the Smart Irrigation System for Precision Farming, enabling automation by acting as an electrically operated switch. It allows the low-power ESP32 microcontroller to control high-power electrical devices, such as the water pump, security alarm, and lighting system, ensuring efficient and precise operation.

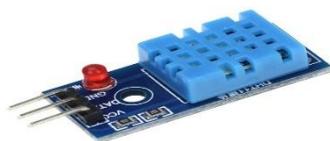


Fig. Relay Module

3. DHT11: The DHT11 sensor plays a crucial role in the Smart Irrigation System for Precision Farming by measuring temperature and humidity levels in the surrounding environment.



Fig. DHT11

4. PIR Sensor: The PIR (Passive Infrared) sensor plays a crucial role in the Smart Irrigation System for Precision Farming by detecting the motion of wild animals near plants. Its primary function is to enhance security and protect crops from potential damage caused by animals, which can be a significant problem in many farming environments.



Fig. PIR Sensor

5. Soil Moisture Sensor: The soil moisture sensor plays a crucial role in the Smart Irrigation System for Precision Farming by ensuring that irrigation is carried out efficiently and only when necessary. Its primary function is to measure the moisture content in the soil, providing real-time data on soil hydration levels.

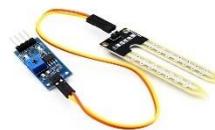


Fig. Soil Moisture Sensor

6. Water Pump: The water pump in a Smart Irrigation System for Precision Farming plays a crucial role in automating the irrigation process, ensuring that crops receive the right amount of water at the right time.



Fig. Water Pump

V. METHODOLOGY

The methodology of the Smart Irrigation System for Precision Farming outlines the working principle of the system, detailing the processes of data acquisition, processing, communication, and automation that ensure efficient irrigation and farm monitoring. The system operates through a network of sensors, a microcontroller, cloud-based data management, and an automated response mechanism.

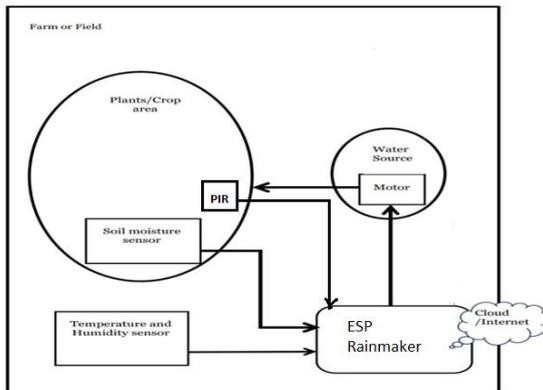


Fig. Block Diagram

The data acquisition process begins with the soil moisture sensor, which takes readings every 5 seconds to assess the water content in the soil. If the moisture level falls below a predefined threshold, the system determines that irrigation is required. Similarly, temperature and humidity sensors monitor the surrounding environmental conditions, updating readings every 10 seconds to provide real-time climate data that helps in better farm management. Additionally, the PIR motion sensor continuously monitors the field for any movement, such as wild animals or unauthorized intrusions, and immediately sends an alert within 1 second upon detecting motion. These sensors work together to ensure accurate and timely data collection.

Once the data is acquired, it is processed by the ESP32 microcontroller, which analyzes the sensor inputs and decides the necessary actions. The microcontroller is programmed with threshold-based automation logic, meaning that irrigation is automatically activated only when the soil moisture level drops below a certain limit. The decision-making mechanism ensures that unnecessary watering is prevented, conserving water and optimizing resource utilization. Similarly, in case of a motion detection event, the ESP32 immediately triggers an alert notification to the farmer's mobile device.

For data transmission and communication, the system utilizes Wi-Fi-based connectivity to send sensor readings to ESP RainMaker Cloud, where they are processed and displayed on a mobile application. The ESP32 sends data at intervals of 500ms to 1 second, depending on network stability, ensuring fast and reliable updates. The mobile application receives real-time updates every 2–3 seconds, allowing farmers to monitor soil conditions, environmental parameters, and security alerts remotely.

The automation logic plays a critical role in system functionality. When the soil moisture level falls below the predefined threshold, the ESP32 sends a signal to the relay module, which in turn activates the water pump within 1–2 seconds. The pump remains active until the soil moisture sensor detects that the optimal moisture level has been reached, at which point the system automatically turns off the pump to prevent overwatering. Likewise, if the PIR motion sensor detects an intrusion, an alert notification is sent within 2 seconds to the farmer's mobile device via the ESP RainMaker app, ensuring immediate action can be taken.

Overall, the system's methodology ensures a seamless, real-time, and energy-efficient irrigation process, reducing water wastage, optimizing resource usage, and enhancing farm security. The combination of automated decision-making, real-time monitoring, and cloud-based control makes the system a highly efficient and intelligent solution for precision farming.

VI. CONCLUSION

The Smart Irrigation System for Precision Farming offers an innovative, efficient, and sustainable solution for modern agriculture by integrating IoT technology, real-time environmental monitoring, and automated control mechanisms. Designed to optimize water management and crop health, the system leverages ESP32 and ESP RainMaker Cloud to ensure seamless data processing and automation. By continuously monitoring soil moisture levels, temperature, and humidity, the system provides precise irrigation control, preventing both overwatering and underwatering, thereby improving water conservation and crop yield.

One of the key advantages of this system is its automated watering mechanism, which significantly

reduces manual intervention and labor costs. When the soil moisture falls below a predefined threshold, the system automatically activates the water pump within 1–2 seconds, ensuring timely irrigation. Once the soil reaches the optimal moisture level, the pump is turned off, effectively minimizing water wastage and promoting sustainable farming practices. This level of automation not only enhances efficiency but also allows farmers to remotely monitor and control irrigation using a mobile application, reducing the need for physical presence in the field.

REFERENCES

- [1] Dr. K. Rama Krishna Reddy, —Improved protocol design with security and QoS over MANET, IJSRCSEIT, volume 3, issue 1, Feb-2018.
- [2] D. Venkatesk, A Subhramanyam, —Survey on Routing Protocols for Manet based Mobility, IJICSE, vol 4, issue 3, May-June 2017, page no. 93-96.
- [3] J. Andrews, S. Shakkottai, R. Heath, N. Jindal, M. Haenggi, R. Berry, D Guo, M. Neely, S. Weber, S. Jafar, and A. Yener, —Rethinking information theory for mobile ad hoc networks, IEEE Commun. Mag., vol. 46, no. 12, pp. 94–101, Dec. 2008.
- [4] A. Goldsmith, M. Effros, R. Koetter, M. Medard, A. Ozdaglar, and L. Zheng, —Beyond shannon: the quest for fundamental performance limits of wireless ad hoc networks, IEEE Commun. Mag., vol. 49, no. 5, pp. 195–205, May 2011
- [5] J. Zhang, J. Chen, and Y. Sun, —Transmission power adjustment of wireless sensor networks using fuzzy control algorithm, Wireless Commun. Mobile Comput., vol. 9, no. 6, pp. 805–818, June 2009. [6] Y. Zhuang, J. Pan, and L. Cai, —Minimizing energy consumption with probabilistic distance distributions in wireless sensor networks, in 2010 INFOCOM.
- [7] M. Grossglauser and D. N. Tse, —Mobility increases the capacity of ad hoc wireless networks, in 2001 INFOCOM.
- [8] A. E. Gamal, J. Mammen, B. Prabhakar, and D. Shah, —Optimal throughput-delay scaling in wireless networks—part I: the fluid model, IEEE Trans. Inf. Theory, vol. 52, no. 6, pp. 2568–2592, June 2006. [9] J. Mammen and D. Shah, —Throughput and delay in random wireless networks with restricted mobility, IEEE Trans. Inf. Theory, vol. 53, no. 3, pp. 1108–1116, 2007.
- [10] R. M. de Moraes, H. R. Sadjadpour, and J. Garcia-Luna-Aceves, —Throughput-delay analysis of mobile ad-hoc networks with a multicopy relaying strategy, in 2004 SECON.
- [11] D. M. Shila and Y. Cheng, —Ad hoc wireless networks meet the infrastructure: mobility, capacity and delay, in 2012 INFOCOM.
- [12] E. Perevalov and R. S. Blum, —Delay-limited throughput of ad hoc networks, IEEE Trans. Commun., vol. 52, no. 11, pp. 1957–1968, Nov. 2004.
- [13] X. Lin, G. Sharma, R. R. Mazumdar, and N. B. Shroff, —Degenerate delay-capacity tradeoffs in ad-hoc networks with brownian mobility, IEEE/ACM Trans. Netw., vol. 52, no. 6, pp. 2777–2784, June 2006.
- [14] M. J. Neely and E. Modiano, —Capacity and delay tradeoffs for ad-hoc mobile networks, IEEE Trans. Inf. Theory, vol. 51, no. 6, pp. 1917–1936, June 2005.
- [15] R. Uргаonkar and M. J. Neely, —Network capacity region and minimum energy function for a delay-tolerant mobile ad hoc network, IEEE/ACM Trans. Netw., vol. 19, no. 4, pp. 1137–1150, Aug. 2011.
- [16] J. Gao, J. Liu, X. Jiang, O. Takahashi, and N. Shiratori, —Exact capacity study for a class of manets, in 2012 ICC.
- [17] J. Liu, X. Jiang, H. Nishiyama, and N. Kato, —Delay and capacity in ad hoc mobile networks with f-cast relay algorithms, IEEE Trans. Wireless Commun., vol. 10, no. 8, pp. 2738–2751, Aug. 2011.
- [18] J. Liu, J. Gao, X. Jiang, H. Nishiyama, and N. Kato, —Capacity and delay of probing-based two-hop relay in MANETs, IEEE Trans. Wireless Commun., vol. 11, no. 11, pp. 4172–4183, Nov. 2012.
- [19] Y. Chen, J. Liu, X. Jiang, and O. Takahashi, —Throughput analysis in mobile ad hoc networks with directional antennas, ad hoc networks, 2012, to be published.
- [20] M. Li and Y. Liu, —Rendered path: range-free localization in anisotropic sensor networks with holes, in 2007 MobiCom.
- [21] M. Li and Y. Liu, —Rendered path: range-free localization in anisotropic sensor networks with holes, in 2007 MobiCom.