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Design and Implementation of a Smart Agricultural Robotic System Using Lora-Based IOT Communication

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Abstract: *The proposed Smart Agricultural Robotic System using LoRa-Based IoT Communication is designed to improve modern farming through automation and intelligent monitoring. The system integrates an ESP32 microcontroller, environmental sensors, LoRa communication modules, relay-controlled actuators, and DC motors to perform agricultural tasks such as irrigation, seed sowing, spraying, and field monitoring. Sensors continuously monitor parameters like temperature, humidity, rainfall, and soil conditions to support real-time decision-making. LoRa technology enables long-range and low-power wireless communication suitable for large agricultural fields. The system supports both autonomous and remote-controlled operation, helping reduce labor dependency, optimize water usage, improve crop productivity, and support precision farming practices. Experimental results show reliable communication, effective robotic movement, and efficient agricultural automation*

Keywords: Smart Agriculture, Agricultural Robot, LoRa Communication, Internet of Things (IoT), Precision Farming, ESP32, Automated Irrigation, Environmental Monitoring

I. INTRODUCTION

Agriculture is one of the most important sectors for economic growth and food production. Traditional farming methods mainly depend on manual labor, excessive water usage, and continuous field monitoring, which often reduce productivity and increase operational cost [1]. In recent years, the advancement of Internet of Things (IoT), robotics, and wireless communication technologies has introduced smart farming solutions for improving agricultural efficiency and sustainability [2]. Smart agriculture helps farmers monitor environmental conditions, automate farming activities, and optimize resource utilization through intelligent systems [3].

Modern precision farming systems use sensors, embedded controllers, and wireless communication networks to collect real-time environmental data such as temperature, humidity, soil moisture, and rainfall conditions [4]. These technologies support automated irrigation, crop monitoring, spraying, and seed sowing operations with minimal human intervention [5]. Automation in agriculture not only reduces labor dependency but also improves crop productivity and water management efficiency [6].

Among various wireless communication technologies, LoRa (Long Range) communication has gained significant importance in smart agriculture applications because of its long communication range and low power consumption [7]. LoRa technology enables reliable wireless communication in large agricultural fields and remote rural environments where traditional communication systems such as Wi-Fi and Bluetooth are less effective [8]. The integration of LoRa with IoT devices allows farmers to remotely monitor and control agricultural operations in real time [9].

The proposed project, "Design and Implementation of a Smart Agricultural Robotic System Using LoRa-Based IoT Communication," focuses on developing an intelligent robotic platform capable of performing agricultural tasks such as irrigation, seed sowing, spraying, and environmental monitoring [10]. The system integrates ESP32 microcontrollers,

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environmental sensors, LoRa modules, relay circuits, and DC motors to provide an energy-efficient and cost-effective solution for precision farming applications.

II. PROBLEM STATEMENT

Traditional farming methods require high manual labor, excessive water usage, and continuous field monitoring, which reduce agricultural efficiency and increase operational cost. Farmers also face difficulties in monitoring large agricultural fields and managing irrigation effectively due to limited communication infrastructure. Existing automation systems mainly support single-purpose operations and short-range communication technologies, making them unsuitable for modern precision farming. Therefore, there is a need for a smart agricultural robotic system that can automate farming tasks, monitor environmental conditions in real time, and provide reliable long-range communication using LoRa-based IoT technology to improve productivity, reduce labor dependency, and optimize resource utilization.

III. OBJECTIVES

- To design and develop a smart agricultural robotic system for automated farming operations.
- To monitor environmental parameters such as temperature, humidity, rainfall, and soil conditions using sensors.
- To implement LoRa-based IoT communication for long-range wireless monitoring and control.
- To automate irrigation and other agricultural activities using intelligent decision-making techniques.
- To reduce manual labor, conserve water resources, and improve overall agricultural productivity.

IV. LITERATURE SURVEY

Dhavale et al. (2025) presented a smart agriculture monitoring system in their paper *"Smart Agriculture Using LoRa System,"* where they integrated environmental sensors, ESP controllers, and LoRa communication for long-range agricultural monitoring and automated irrigation. The system enabled real-time monitoring of soil moisture, temperature, humidity, and rainfall conditions using cloud platforms such as ThingSpeak and Blynk. Their approach improved water management and communication efficiency in large agricultural fields. However, the system mainly focused on irrigation monitoring and did not include robotic automation or multipurpose farming operations.

Jakhotiya et al. (2021) proposed a LoRaWAN-based irrigation system in their paper *"Application of LoRaWAN Technology in Farm for Irrigation System."* The authors used Arduino controllers and environmental sensors to automate irrigation processes through long-range wireless communication. The system reduced manual intervention and optimized water utilization in rural farming areas. However, the proposed model lacked autonomous robotic movement and intelligent decision-making mechanisms for advanced agricultural automation.

Enock et al. (2025) introduced a precision farming system in their paper *"LoRa-Based Smart Agriculture Monitoring and Automatic Irrigation System,"* where they combined ESP32 controllers, multiple environmental sensors, and LoRa communication for automated irrigation and remote monitoring. The system successfully transmitted environmental data over long distances with low power consumption. However, the work mainly concentrated on monitoring and irrigation applications and did not support robotic navigation or multifunctional agricultural tasks.

Arshad et al. (2022) developed a decision support system in their paper *"Implementation of a LoRaWAN Based Smart Agriculture Decision Support System for Optimum Crop Yield."* The system integrated sensors for soil moisture, temperature, humidity, pH, and nutrient monitoring to provide intelligent irrigation and fertilizer recommendations. Their approach improved crop management and resource utilization through cloud-based monitoring platforms. However, the system involved higher hardware complexity and lacked robotic farming functionalities.

Aldhaheri et al. (2024) discussed the role of LoRa technology in smart farming in their paper *"LoRa Communication for Agriculture 4.0: Opportunities, Challenges, and Future Directions."* The study analyzed LoRa network architectures, communication protocols, and IoT-based agricultural systems while comparing LoRa with Wi-Fi, ZigBee, and cellular technologies. The paper highlighted the advantages of low-power and long-range communication for precision agriculture. However, the research was mainly survey-based and did not provide practical robotic system implementation.

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Chaya et al. (2025) presented an IoT-enabled agricultural robot in their paper *"IoT Based Robot For Smart Agriculture – Farming,"* where they designed a robotic platform capable of irrigation, spraying, and environmental monitoring using embedded controllers and IoT communication modules. The proposed robot reduced manual labor and improved farming efficiency through automation. However, the system had limited communication range and lacked advanced LoRa-based long-distance communication and autonomous intelligent control features.

Comparison Table

Author & Year	**Method Used**	**Advantages**	**Limitations**
Dhavale et al. (2025)	LoRa smart irrigation system	Long-range monitoring	No robotic system
Jakhotiya et al. (2021)	LoRaWAN irrigation control	Saves water	Limited automation
Enock et al. (2025)	IoT and LoRa monitoring	Real-time monitoring	No robot movement
Arshad et al. (2022)	Smart decision support system	Better crop management	High complexity
Aldhaheri et al. (2024)	LoRa agriculture survey	Energy efficient communication	No practical implementation
Chaya et al. (2025)	IoT farming robot	Reduces manual labor	Limited communication range

V. WORKING OF SYSTEM

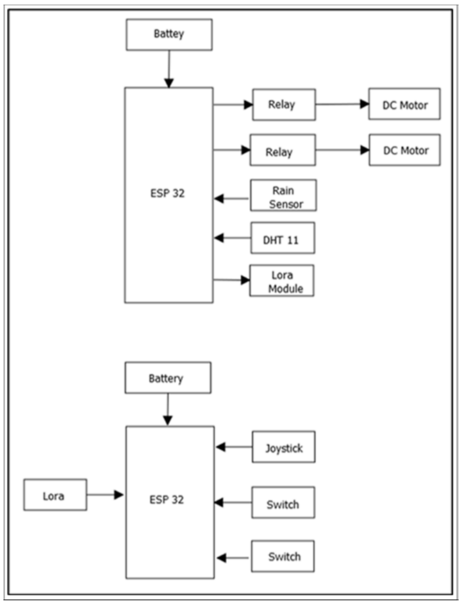

Fig 1: Design of the system

1. Power Supply Unit

The entire system is powered using rechargeable batteries connected to both ESP32 controllers. The battery provides electrical power to sensors, LoRa modules, relay circuits, and DC motors for continuous agricultural operation.

2. ESP32 Controller Operation

The ESP32 acts as the main control unit of the system. It receives sensor data, processes information, controls relays and motors, and manages LoRa communication between the field unit and remote control unit.

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3. Environmental Monitoring

The DHT11 sensor continuously measures temperature and humidity conditions from the agricultural field. The rain sensor detects rainfall or water droplets and sends real-time environmental information to the ESP32 controller.

4. Relay and Motor Control

Relay modules are connected to the ESP32 for controlling DC motors and agricultural mechanisms. Based on sensor conditions or user commands, the relays activate or deactivate the motors for robotic movement and farming operations.

5. Robotic Movement

DC motors provide forward, backward, left, and right movement of the agricultural robot. The robot can also perform farming tasks such as irrigation, seed sowing, spraying, and field monitoring.

6. LoRa Communication System

LoRa modules establish long-range wireless communication between the field unit and the remote control unit. Sensor data and control commands are transmitted over long distances with low power consumption.

7. Remote Control Unit

The second ESP32 controller acts as the remote control section. A joystick is used for controlling robot movement, while switches are used to activate or stop agricultural operations remotely.

8. Automatic Irrigation Operation

When low soil moisture or dry environmental conditions are detected, the ESP32 automatically activates irrigation through relay-controlled mechanisms. If rainfall is detected, irrigation is stopped automatically to conserve water.

9. Real-Time Monitoring and Automation

The system continuously monitors field conditions and performs intelligent farming operations automatically. This reduces manual labor, improves water management, and increases agricultural productivity.

VI. SYSTEM DESIGN

1. System Overview:

The proposed Smart Agricultural Robotic System using LoRa-Based IoT Communication is designed to automate agricultural activities and improve farming efficiency through intelligent monitoring and control. The system integrates ESP32 microcontrollers, environmental sensors, LoRa communication modules, relay circuits, DC motors, and robotic mechanisms into a single automated platform.

The agricultural field unit continuously monitors environmental parameters such as temperature, humidity, and rainfall using DHT11 and rain sensors. The collected sensor data is processed by the ESP32 controller, which performs automatic decision-making for irrigation and other farming operations.

1. Power Supply Module

The power supply module provides electrical energy to all components of the system. Rechargeable batteries are used to power the ESP32 controllers, sensors, LoRa modules, relay circuits, and DC motors. This module ensures stable and continuous operation of the agricultural robotic system in remote farming areas.

2. ESP32 Control Module

The ESP32 microcontroller acts as the central processing and control unit of the system. It receives data from sensors, processes environmental information, controls relays and motors, and manages communication through the LoRa module. The ESP32 enables both autonomous and remote-controlled agricultural operations.

3. Sensor Monitoring Module

This module consists of the DHT11 sensor and rain sensor for environmental monitoring. The DHT11 sensor measures temperature and humidity, while the rain sensor detects rainfall conditions. The collected data helps the system make intelligent decisions for irrigation and field management.

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4. LoRa Communication Module

The LoRa module provides long-range wireless communication between the agricultural robotic node and the remote control unit. It transmits sensor data and receives control commands over large agricultural fields with low power consumption and reliable connectivity.

5. Relay Control Module

The relay module acts as an electrically controlled switching unit. It isolates the low-voltage ESP32 controller from high-current devices such as DC motors and irrigation mechanisms. The relay activates or deactivates agricultural operations based on control signals.

6. DC Motor Driver Module

The DC motor module is responsible for robotic movement and farming task execution. The motors enable forward, backward, left, and right movement of the robot and support operations such as seed sowing, spraying, and irrigation assistance.

7. Remote Control Module

The remote control module includes another ESP32 controller, joystick, and switches. The joystick controls robotic movement, while switches are used to activate or deactivate farming operations remotely through LoRa communication.

8. Automation and Decision-Making Module

This module performs intelligent control operations based on sensor data. The ESP32 continuously analyzes environmental conditions and automatically controls irrigation and robotic functions to improve water efficiency and reduce manual intervention.

VII. RESULTS

5.1 System Performance in Real-Time Detection

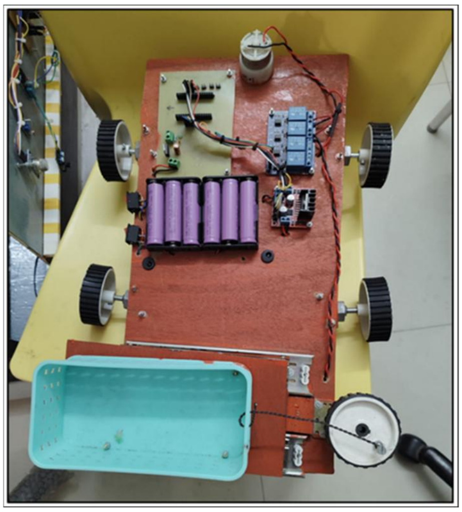

Fig 2: Prototype Model 1

The developed Smart Agricultural Robotic System was successfully implemented and tested using the fabricated prototype model shown above. The prototype consists of a four-wheel robotic chassis integrated with major hardware components such as the ESP32 controller, relay module, rechargeable battery pack, DC motors, motor driver circuit, and seed sowing mechanism. The hardware arrangement demonstrates proper integration of sensing, control, communication, and robotic actuation modules within a single agricultural platform.

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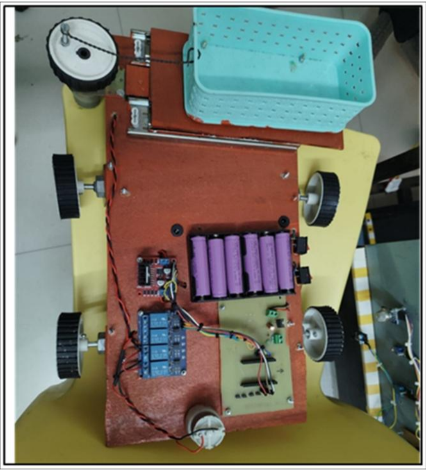

Fig.3 Prototype Model 2

During experimental testing, the robotic system successfully performed forward, backward, left, and right movement with stable operation on flat surfaces. The relay-controlled DC motors responded accurately to control commands, providing smooth robotic movement and reliable task execution. The integrated seed sowing mechanism operated effectively while the robot was in motion, confirming the successful implementation of automated agricultural functionality.

The battery system provided continuous power supply to all electronic modules, ensuring stable operation of the robot without interruption. The ESP32 controller efficiently processed sensor data and controlled agricultural operations in real time. The overall prototype demonstrated reliable performance, low power consumption, efficient robotic movement, and suitability for precision farming applications such as seed sowing, irrigation assistance, spraying, and field monitoring. The experimental results confirm that the proposed system is a cost-effective and intelligent solution for modern smart agriculture.

VIII. CONCLUSION

The proposed Smart Agricultural Robotic System using LoRa-Based IoT Communication was successfully designed and implemented for precision farming applications. The system integrated ESP32 microcontrollers, environmental sensors, LoRa communication modules, relay circuits, and DC motors to automate agricultural operations such as irrigation, seed sowing, spraying, and field monitoring. The developed robotic platform demonstrated reliable performance in real-time environmental monitoring, long-range wireless communication, and autonomous farming operations. The use of LoRa technology provided stable low-power communication suitable for large agricultural fields and remote farming areas. Experimental results confirmed that the system reduced manual labor, improved water management, optimized resource utilization, and increased farming efficiency. The proposed system offers a cost-effective, energy-efficient, and scalable solution for modern smart agriculture and sustainable farming practices.

IX. FUTURE SCOPE

The proposed Smart Agricultural Robotic System can be further enhanced by integrating advanced technologies such as Artificial Intelligence (AI), Machine Learning (ML), and Computer Vision for intelligent crop monitoring, disease detection, and yield prediction. Additional environmental sensors such as soil pH, NPK, and gas sensors can be incorporated to improve precision farming and environmental analysis. The system can also be upgraded with GPS and autonomous navigation technology to enable fully automatic robotic movement in large agricultural fields without manual control. Integration of cloud computing and mobile applications can provide advanced real-time monitoring, data analytics, and remote supervision facilities for farmers. Solar-powered energy systems may also be added to improve energy efficiency and support sustainable farming operations.

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