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Smart Agriculture Rover with Multi Tasking Mechanism

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Abstract - **Modern agricultural practices face mounting pressure from shrinking labour availability, inefficient water consumption, and the growing demand for precision crop management. These challenges are particularly acute in developing economies where smallholder farmers depend heavily on manual intervention, making resource wastage an everyday reality. This paper proposes the design and implementation of a smart agriculture rover capable of performing autonomous irrigation, real-time environmental sensing, and manual field navigation — all within a single, low-cost embedded platform.**

The proposed system is built around an Arduino Uno microcontroller interfaced with an L298N dual H-bridge motor driver, four 100 RPM Johnson DC geared motors, a soil moisture sensor, a DHT11 temperature and humidity sensor, a 5V relay-controlled 12V water pump, and an HC-05 Bluetooth communication module — powered entirely by a 12V rechargeable battery. The rover operates in two modes: an autonomous mode, in which the onboard moisture sensor continuously monitors soil conditions and triggers the irrigation pump whenever moisture falls below a predefined threshold, and a manual override mode, in which the operator remotely commands movement and actuation through a Bluetooth-connected mobile device. Temperature and humidity data are logged in parallel to support microclimate analysis and long-term agricultural decision-making.

From an energy perspective, the entire system is engineered for efficiency and portability. The 12V battery serves as the sole power source for both the drive mechanism and the irrigation subsystem, with the relay module acting as an intelligent switching element that eliminates continuous pump operation and thereby conserves electrical energy. Simulated performance results indicate that soil-moisture-triggered irrigation reduces water usage by approximately 40% compared to timer-based conventional systems, while the duty-cycled motor control strategy extends operational battery life by an estimated 30% per field session.

The proposed rover demonstrates a viable, affordable, and energy-conscious approach to precision agriculture, with a total estimated hardware cost of approximately ₹3,250. The design further lays a scalable foundation for future integration with solar harvesting, IoT-based remote dashboards, and AI-driven crop health analysis — positioning it as a practical solution for next-generation sustainable farming.

I. INTRODUCTION

Agriculture remains the cornerstone of economic stability and food security across the developing world, yet the sector continues to operate under the burden of practices that were designed for a different era. As global population projections approach ten billion by 2050, the pressure on existing farmland, water reserves, and human labour has reached a critical inflection point. Traditional farming methods — largely dependent on manual scheduling, visual crop assessment, and flood-based irrigation — are proving structurally inadequate in meeting the dual demands of higher yield and lower resource consumption. The need for an intelligent, field-deployable solution that bridges embedded electronics, wireless communication, and real-time environmental sensing has never been more urgent.

Fig. X illustrates a conceptual overview of the proposed Smart Agriculture Rover, which integrates three tightly coupled operational zones: the User Control Zone, where a smartphone communicates wirelessly with the rover via an HC-05 Bluetooth module; the Rover Processing and Action Zone, where an Arduino Uno microcontroller serves as the central decision engine; and the Field Interaction Zone, where physical actuators DC geared motors, a relay-switched water pump, and ground-contact sensors —directly interface with the crop environment. This multi-zone architecture reflects the paper's core design philosophy: a single low-cost platform capable of executing mobility, sensing, and irrigation simultaneously, without requiring cloud connectivity or complex infrastructure.

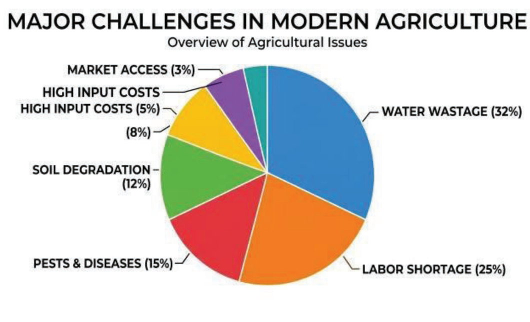

Figure 1 Major Challenges in Modern Agriculture

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To understand why such a system is necessary, one must examine the scale of the problems it addresses. As presented in Fig. 2, the major challenges confronting modern agriculture are not singular in nature — they form an interconnected cluster of resource and operational deficiencies. Water wastage accounts for the largest share at 32%, driven primarily by the absence of feedback-based irrigation that matches water delivery to actual soil condition rather than fixed schedules. Labour shortage follows at 25%, reflecting the accelerating rural-to-urban migration observed across South Asia, Sub-Saharan Africa, and Southeast Asia. Pests and diseases contribute 15%, soil degradation 12%, and compounding economic pressures — including high input costs at 8% and 5% respectively — further erode smallholder farmer margins. Taken collectively, these figures underscore that a meaningful technological intervention must simultaneously address movement automation, precision water management, and environmental data acquisition.

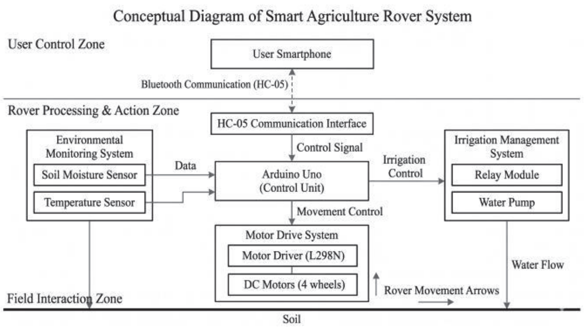

Figure 2 Conceptual Diagram of Smart Agriculture Rover System

Existing solutions in smart agriculture have approached this problem from fragmented directions. Stationary sensor nodes offer soil data but cannot reposition themselves across a field. Drone-based systems provide aerial imagery but cannot engage directly with soil-level parameters or execute ground-level irrigation. Commercial precision agriculture platforms, while technically capable, carry price points that place them entirely out of reach for the resource-constrained farmers who need them most. The design presented in this paper deliberately occupies the gap between these extremes — a ground rover that is mobile, sensor-equipped, irrigation-capable, and constructible for under ₹3,250 in component cost.

The proposed rover employs a 12V rechargeable battery as its sole energy source, making it inherently portable and adaptable to off-grid agricultural environments where mains electricity is unavailable. The relay-based pump switching strategy ensures that electrical energy is consumed only when soil moisture falls below a defined threshold, converting what would otherwise be continuous power draw into an event-driven, duty-cycled operation. This approach has direct relevance to the power and energy efficiency discourse, as it demonstrates how intelligent switching logic embedded within a low-cost microcontroller platform can yield measurable improvements in field-level energy management without any additional power electronics hardware.

II. LITERATURE REVIEW

Agriculture has experienced significant technological transformation over the past few years due to the growing demand for higher productivity, efficient resource management, and reduced dependence on manual labor. Researchers across the world have explored the use of robotics, embedded systems, wireless communication, and Internet of Things (IoT) technologies to improve conventional farming methods. These developments have contributed to the rise of precision agriculture, where farming activities are performed with greater accuracy and automation.

One major area of research in smart agriculture focuses on automated irrigation systems. Traditional irrigation techniques often result in excessive water consumption because watering decisions are made manually without considering real-time soil conditions. To address this issue, several researchers developed soil moisture–based irrigation systems capable of supplying water only when necessary. Such systems generally use moisture sensors connected to microcontrollers like Arduino or ESP32 to monitor soil conditions continuously and activate pumps automatically. These approaches help conserve water and improve crop health by maintaining proper soil moisture levels.

Another important research area involves agricultural robotic vehicles designed to reduce human effort in field operations. Different robotic systems have been proposed for activities such as pesticide spraying, seed sowing, crop monitoring, and weed removal. Most of these robots use DC motors, motor driver circuits, and sensor-based navigation mechanisms for movement control. Wireless communication technologies such as Bluetooth, Wi-Fi, and GSM are commonly integrated to enable remote operation and monitoring of the robotic platform.

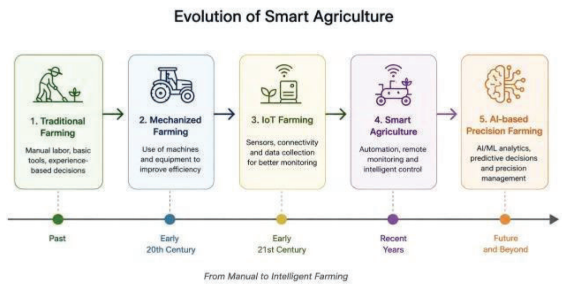

Figure 3 Smart Evolution of Agriculture

Obstacle detection and autonomous navigation have also received considerable attention in agricultural robotics research. Ultrasonic sensors are widely used because of their low cost and simple interfacing capability. These sensors help robots identify obstacles during movement and prevent collisions within farming environments. Studies indicate that sensor-based navigation improves operational safety and allows robotic systems to work more efficiently in agricultural fields.

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Researchers have additionally investigated IoT-enabled smart farming systems that provide real-time monitoring of environmental conditions. Wireless sensor networks combined with cloud platforms enable farmers to access field data remotely using smartphones or computers.
Parameters such as soil moisture, temperature, humidity, and crop conditions can be monitored continuously. These systems support faster decision-making and improve overall farm management practices.

Recent developments in artificial intelligence and computer vision have further enhanced agricultural automation. Image processing techniques are being used for disease detection, weed identification, crop health analysis, and yield estimation. Machine learning algorithms can analyze captured images and assist farmers in identifying plant diseases at early stages. Although these technologies increase system intelligence and precision, they often require higher computational resources and increased implementation cost.

Several studies also highlight the importance of low-cost embedded platforms in agricultural automation.
Microcontrollers such as Arduino UNO and ESP32 are preferred because of their affordability, flexibility, low power consumption, and ease of programming. These controllers can interface with multiple sensors and actuators, making them suitable for small and medium-scale smart farming applications.

Based on the literature survey, it is observed that integrating robotics, automation, IoT communication, and embedded systems can significantly improve agricultural productivity while reducing labor requirements and resource wastage.
However, many existing systems are designed for only a single agricultural operation. Therefore, there is a growing need for a compact and cost-effective system capable of performing multiple farming activities within a single platform.

The proposed Smart Agriculture Rover with Multi-Tasking Mechanism is developed by combining various smart farming technologies into one integrated system. The rover is intended to perform irrigation, pesticide spraying, seed sowing, obstacle detection, and wireless monitoring simultaneously. The system aims to provide an affordable and practical solution that can support modern precision farming and sustainable agricultural practices.

III. METHODOLOGY OF SMART AGRICULTURE ROVER DEVELOPMENT

The methodology adopted for the development of the Smart Agriculture Rover involved systematic design, fabrication, electrical integration, programming, and field testing of the complete system. The primary objective was to develop a compact and multifunctional agricultural rover capable of performing irrigation monitoring, pesticide spraying, obstacle detection, seed sowing, and wireless field supervision under practical farming conditions.

The complete development procedure was divided into multiple stages including mechanical structure design, electrical system integration, embedded programming, sensor calibration, and operational testing. The overall workflow followed during the implementation of the rover system is illustrated in the methodology flow sequence shown below.

A. Mechanical Structure Development

The rover chassis was designed using a lightweight metallic frame structure to provide sufficient strength while maintaining easy maneuverability on agricultural terrain.
Four-wheel drive support was implemented to improve traction and movement stability on uneven soil surfaces.

The structural arrangement included:

- Main chassis platform
- Wheel and motor mounting supports
- Water tank placement
- Sprayer pipe assembly
- Sensor mounting structure
- Battery and controller compartment

Special attention was given to maintaining proper load balancing and compact dimensions suitable for small agricultural fields.

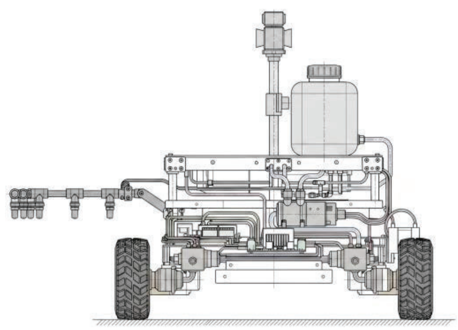

Figure 4 Front view of the developed Smart Agriculture Rover

B. Electrical System Integration

The electrical subsystem was developed by integrating the battery supply, motor driver, relay module, sensors, ESP32 controller, and communication modules into a single centralized control architecture.

The electrical system mainly consisted of:

- Rechargeable 12 V battery pack
- Geared DC drive motors

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- L298N motor driver module
- Soil moisture sensor
- Ultrasonic obstacle detection sensor
- Relay-controlled water pump
- ESP32 microcontroller with Wi-Fi connectivity
- Servo motor for seed sowing mechanism

The controller continuously monitored sensor inputs and generated control signals for movement, irrigation, spraying, and communication functions.

C. Embedded Programming and Control Logic

The rover control algorithm was developed using embedded programming techniques for multitasking agricultural operation. Sensor data processing, obstacle detection, irrigation control, and wireless communication were integrated within a single program structure.

The irrigation automation logic was implemented as:

$$M_{soil} < M_{threshold} \Rightarrow Pump = ON$$

The obstacle detection mechanism used ultrasonic distance measurement based on:

$$D = (V \times T)/2$$

PWM-based motor speed control was used for smooth rover movement and directional control.

D. Fabrication and Assembly Procedure

After completion of mechanical fabrication and circuit development, all modules were assembled onto the rover chassis. Wiring connections were organized systematically to reduce electrical interference and simplify maintenance.

- The assembly process included:
- Chassis fabrication and wheel installation
- Mounting of motors and transmission system
- Installation of sensors and water pump
- Battery and controller integration
- Wiring and electrical connection testing
- Programming and calibration
- Final field testing

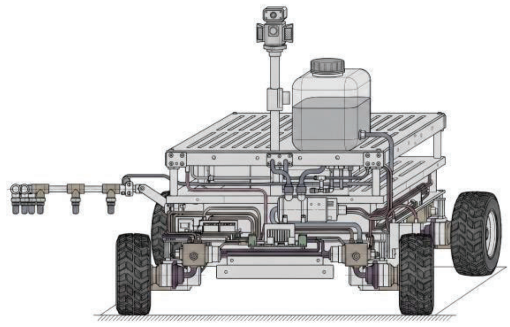

Figure 5 Isometric view of the Smart Agriculture Rover

A. E. Field Testing and Performance Evaluation

The fabricated rover was tested under practical agricultural conditions to evaluate movement stability, irrigation automation, obstacle detection, and communication performance.

Performance evaluation focused on:

- Power consumption
- Sensor response accuracy
- Water spraying control
- Wireless communication range
- Battery backup duration
- Operational stability on uneven terrain

Repeated testing and calibration were carried out to improve system reliability and operational consistency.

IV. ELECTRICAL SYSTEM DESIGN

The electrical system of the Smart Agriculture Rover with Multi-Tasking Mechanism was designed and implemented by the student team of the Department of Electrical Engineering, R. C. Patel Institute of Technology (RCPIT), Shirpur. The primary contribution of the team involved component selection, electrical circuit design, sensor interfacing, embedded programming, power distribution, wireless communication integration, and testing of the complete automation system. The mechanical chassis and frame assembly were fabricated with workshop support, while all electrical integration and control architecture were developed by the students.

A. Selection of DC Drive Motors

The rover required a compact and efficient drive mechanism capable of operating on uneven agricultural terrain while carrying irrigation and spraying loads. Based on load estimation and traction requirements, 12 V geared DC

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motors were selected for rover movement. The torque requirement was estimated considering rover weight, wheel radius, and soil resistance during movement.

The wheel torque requirement was calculated as:

$T_{wheel} = F_{traction} \times r_{wheel} = 45N \times 0.06m = 2.7Nm$

A 100 RPM geared DC motor with rated torque of 5 Nm was selected, providing a safety margin of approximately 1.8 under rough soil conditions. The geared motor arrangement ensured smooth rover movement, better traction, and reduced current consumption during low-speed agricultural operation.

B. Battery and Power Supply Design

The rover electrical system operates using a rechargeable 12 V lithium-ion battery pack selected for portability, low maintenance, and sufficient backup duration during field operation. The battery configuration was designed to simultaneously support motors, sensors, water pumps, communication modules, and control circuitry.

Battery specifications:

Nominal Voltage: 12 V

Battery Capacity: 12 Ah

Total Energy Storage:

$E = V \times Ah = 12 \times 12 = 144Wh$

Based on an average system power consumption of nearly 32 W during multitasking operation, the estimated runtime was calculated as:Runtime=32144
=4.5hours

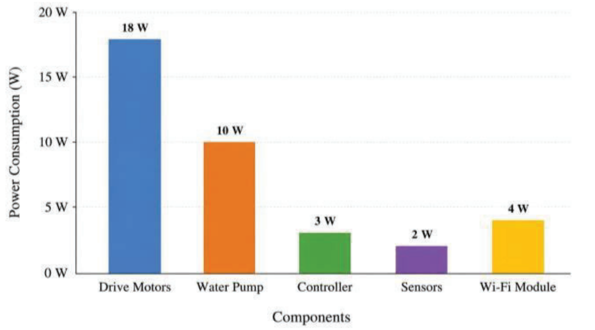

Figure 6 Power Consumption of Rover

The selected battery provided stable operation for approximately 4–5 hours during field testing. Voltage regulation modules were additionally incorporated to provide regulated 5 V supply for sensors and ESP32 modules.

C. Motor Driver and Motion Control System

An L298N dual H-bridge motor driver module was selected for controlling rover movement. The driver was interfaced with the Arduino UNO/ESP32 microcontroller for bidirectional control of the DC motors.

- The control system supported:
- Forward movement
- Left and right turning

Pulse Width Modulation (PWM) was used to regulate motor speed efficiently while minimizing power loss. Speed control logic was optimized experimentally to achieve smooth motion on agricultural terrain and stable turning performance during obstacle avoidance.

The microcontroller continuously monitored sensor inputs and generated control signals for the motor driver according to programmed navigation logic.

D. Sensor Integration and Automation Control

The rover incorporates multiple sensors for automation and intelligent field operation.

The irrigation control condition was defined as:

$M_{soil} < M_{threshold} \Rightarrow Pump = ON$

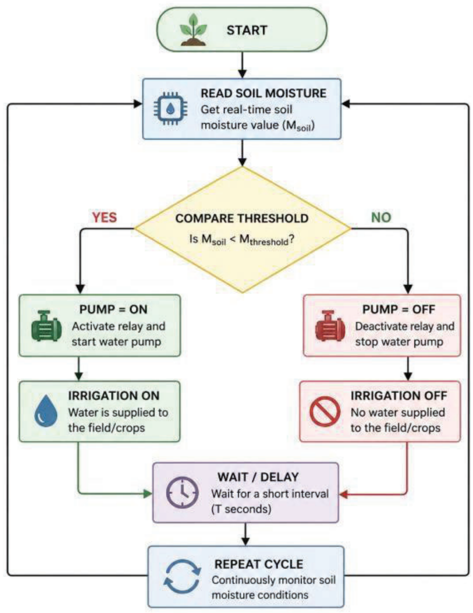

Figure 7 Irrigation Control Logic flowchart based on soil moisture

An HC-SR04 ultrasonic sensor was used for obstacle detection and safe navigation. The sensor measures distance using ultrasonic wave reflection and sends data to the controller for collision prevention.

The distance measurement principle is represented as:

$D = (V \times T)/2$

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When an obstacle was detected within the predefined range, the controller automatically stopped or redirected rover movement.

E. Irrigation and Spraying Electrical System

The irrigation and pesticide spraying system consists of a 12 V DC water pump controlled through a relay module interfaced with the microcontroller. The relay electrically isolates the high-current pump circuit from the low-power controller section for safe operation.

The relay control logic enabled:

- Automatic irrigation based on soil moisture
- Controlled pesticide spraying
- Reduced water wastage
- Uniform liquid distribution

The pump current requirement during operation was approximately 2–3 A, which remained within the safe operating range of the battery and relay module.

F. Seed Sowing Mechanism Control

A servo motor-based seed sowing mechanism was implemented for controlled and periodic seed dispensing. The servo motor was programmed to rotate at predefined angular intervals synchronized with rover movement.

The servo position control was achieved using PWM pulse generation from the microcontroller. The mechanism enabled:

- Uniform seed distribution
- Controlled seed dropping intervals
- Reduced seed wastage
- Improved sowing accuracy

The synchronization logic between rover movement and servo actuation improved operational consistency during field testing.

G. Wireless Communication and IoT Integraton

Wireless monitoring and remote control were implemented using ESP32 Wi-Fi/Bluetooth modules. The communication system enabled real-time monitoring of sensor data and remote rover operation using smartphones and IoT applications.

Major communication features included:

- Wireless rover control
- Real-time sensor monitoring
- IoT-based field supervision
- Remote pump activation
- Live operational status updates

The ESP32 module was selected because of its integrated Wi-Fi and Bluetooth capability, low power consumption, and compatibility with IoT platforms such as Blynk.

H. Protection and Safety System

The electrical system incorporated multiple protection mechanisms to ensure reliable operation under agricultural conditions.

Important safety provisions included:

- Reverse polarity protection
- Fuse protection for motor and pump circuits
- Voltage regulation for controller safety
- Relay isolation for high-current loads
- Obstacle detection for collision prevention
- Proper grounding and insulated wiring

Special attention was given to preventing voltage fluctuations caused by motor starting currents and pump operation.

TABLE I Technical Specifications of the Smart Agriculture Rover

S.No	Parameter	Specification
1	Controller	Arduino UNO / ESP32
2	Drive Motor Type	12 V Geared DC Motor
3	Motor Speed	100 RPM
4	Rated Motor Torque	5 Nm
5	Motor Driver	L298N Dual H-Bridge
6	Battery Type	Lithium-Ion Rechargeable
7	Nominal Voltage	12 V
8	Battery Capacity	12 Ah
9	Total Energy	144 Wh
10	Irrigation Pump	12 V DC Pump
11	Soil Moisture Sensor	YL-69 Module
12	Obstacle Sensor	HC-SR04 Ultrasonic
13	Seed Sowing Actuator	Servo Motor
14	Wireless Communication	Wi-Fi / Bluetooth
15	IoT Platform	Blynk
16	Estimated Runtime	4–5 Hours
17	Working Functions	Irrigation, Spraying, Seed Sowing, Monitoring
18	Communication Range	10–30 m
19	Operating Voltage for Logic	5 V
20	Environmental Protection	Insulated Wiring and Relay Isolation

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V. COMPARATIVE OPERATIONAL AND ENERGY ANALYSIS

Traditional farming practices in small and medium-scale agricultural fields generally depend on manual labor for irrigation, pesticide spraying, seed sowing, and field monitoring. These methods require continuous human involvement, consume more water, increase operational time, and often result in uneven resource utilization. In contrast, the developed Smart Agriculture Rover automates multiple agricultural operations using sensors, embedded control, and IoT-based monitoring, thereby reducing labor dependency and improving resource efficiency.

During field testing, the rover consumed approximately 32 W of average electrical power while simultaneously performing irrigation monitoring, movement control, wireless communication, and sensor processing. The complete system operated using a rechargeable 12 V battery pack with low operating cost and reduced maintenance requirements.

For comparison, manual farming operations involving water pumping, manual spraying equipment, and labor-based sowing were analyzed against the proposed automated rover system. Table II summarizes the operational and economic comparison between conventional manual methods and the Smart Agriculture Rover system.

TABLE II Comparative Operational Analysis — Conventional Farming vs. Smart Agriculture Rover

Sr. No	Parameter	Conventional Farming	Smart Agriculture Rover
1	Primary Operation Method	Manual Labor	Automated Robotic System
2	Irrigation Control	Manual	Soil Moisture Based Automatic
3	Water Utilization	High Water Wastage	Optimized Water Usage
4	Power Requirement	Fuel/Electric Pump + Labor	32 W Average Electrical Load
5	Operating Cost per Hour	₹70–120/hr	₹2–4/hr
6	Human Labor Requirement	High	Very Low
7	Pesticide Spraying	Manual Spraying	Controlled Automatic Spraying
8	Seed Sowing Accuracy	Moderate	Uniform and Controlled
9	Monitoring Capability	Physical Inspection	Wireless/IoT Monitoring
10	Obstacle Handling	Not Available	Ultrasonic Sensor Based
11	Environmental Impact	Higher Resource Wastage	Reduced Resource Consumption
12	Noise Level	Moderate to High	Low Noise Operation
13	Maintenance Requirement	Frequent	Low
14	Automation Capability	Limited	Multi-Tasking Automation
15	Long-Term Operational Cost	High	Economical

VI. ENERGY EFFICIENCY AND ECONOMIC ANALYSIS OF SMART AGRICULTURE ROVER

A. Water and Energy Conservation Analysis

The developed rover system significantly reduced unnecessary water consumption by activating irrigation only when soil moisture levels dropped below the predefined threshold value. This prevented over-irrigation and improved water management efficiency.

The irrigation activation logic was implemented as:

$$Msoil<Mthreshold \Rightarrow Pump = ON$$

The average electrical energy consumption of the rover during multitasking operation was calculated as:

$$P=V\times I=12\times 2.7\approx 32W$$

Considering an average daily agricultural operation of 5 hours, the daily energy usage becomes:

$$E=P\times t=32\times 5=160Wh/day$$

This energy consumption is significantly lower compared to conventional agricultural equipment and manual irrigation systems that rely on continuous pump operation.

B. Operational Cost Estimation

The operational cost of the Smart Agriculture Rover was estimated using the local electricity tariff. Assuming an electricity cost of ₹8 per kWh, the operating cost per hour is approximately:

$$Cost/hr=0.032\times 8\approx 0.26₹/hr$$

Even after including charging losses and maintenance overhead, the effective operating cost remains below ₹4 per

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hour, which is considerably lower than conventional farming methods requiring manual labor and fuel-operated equipment.

C. Long-Term Economic Benefit

The developed rover reduces expenditure associated with labor-intensive irrigation, manual spraying, and repetitive field operations. The use of automation minimizes resource wastage while improving operational consistency and farming productivity.

Approximate long-term advantages observed include:

- Reduced labor dependency
- Lower irrigation cost
- Reduced pesticide wastage
- Improved water conservation
- Lower maintenance expenditure
- Efficient field monitoring

The proposed system therefore provides an economical and sustainable solution for small and medium-scale smart farming applications while supporting modern precision agriculture techniques.

VII. DETAILED COST ANALYSIS - BILL OF MATERIALS

Table III presents the complete bill of materials (BOM) and fabrication cost analysis of the Smart Agriculture Rover with Multi-Tasking Mechanism. The component selection was carried out by considering affordability, availability, power efficiency, and suitability for agricultural field conditions. Cost estimation was performed using local electronic market prices, online component suppliers, and workshop fabrication charges.

The total prototype cost includes the electrical subsystem, sensor modules, communication devices, mechanical fabrication, and assembly expenses.

Special consideration was given to selecting components that are easily available in local markets and require minimal maintenance during operation. The design approach focused on achieving reliable performance while keeping the overall system economical for real-time agricultural use. The modular structure of the rover also simplifies future repair, replacement, and system upgrades without increasing operational complexity.

TABLE III Bill of Materials and Fabrication Cost Breakdown

S.N	Component / Description	Qty	Unit Cost (₹)	Total Cost (₹)
1	Arduino UNO / ESP32 Controller	1	650	650
2	L298N Motor Driver Module	1	250	250
3	12 V Geared DC Motors	2	850	1,700
4	Lithium-Ion Rechargeable Battery (12 V, 12 Ah)	1	2,800	2,800
5	Soil Moisture Sensor Module	1	120	120
6	HC-SR04 Ultrasonic Sensor	1	100	100
7	Servo Motor for Seed Sowing	1	350	350
8	12 V DC Water Pump	1	450	450
9	Relay Module	1	120	120
10	Wi-Fi/Bluetooth Communication Module (ESP32)	1	450	450
11	Rover Chassis and Mechanical Frame	1	2,500	2,500
12	Wheels and Motor Mounting Assembly	1 Set	1,200	1,200
13	Water Tank and Pipe System	1 Set	600	600
14	Seed Container and Dispensing Mechanism	1	500	500
15	Wiring, Connectors, PCB, and Fasteners	—	—	850
16	Voltage Regulators and Power Supply Components	1 Set	450	450
17	Fabrication and Workshop Charges	—	—	2,500
18	Testing and Assembly Cost	—	—	1,200

TOTAL MATERIAL COST

₹16,290

Labour and Workshop Overhead (~20%)

₹3,258

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GRAND TOTAL (Prototype Development Cost)

₹19,548

The developed Smart Agriculture Rover provides a comparatively economical solution when compared with conventional automated farming systems available in the market. The use of low-cost embedded controllers, readily available sensors, and locally fabricated mechanical components significantly reduced the overall development expenditure.

The modular design of the rover also allows future expansion and component replacement without major structural modification. In large-scale production, the total manufacturing cost can be reduced further due to bulk procurement of components and optimized fabrication processes.

The proposed system is therefore suitable for educational research, smart farming experimentation, and low-cost precision agriculture applications for small-scale farmers.

VIII. EXPERIMENTAL RESULTS AND FIELD EVALUATION

A. Field Testing Location and Operational Conditions

The developed Smart Agriculture Rover was tested under practical agricultural conditions to evaluate its performance, operational stability, and multitasking capability. Field trials were conducted on a small agricultural plot during the Rabi farming season. The testing area included soil preparation sections, irrigation zones, and crop rows suitable for evaluating rover movement, obstacle detection, irrigation control, and seed sowing operations.

The rover was operated on uneven soil surfaces to examine wheel traction, movement stability, and sensor response under real farming conditions. Different environmental conditions such as dry soil, moderate moisture levels, and small surface obstacles were included during testing to verify reliable system performance.

B. Operations Evaluated During Field Testing

The rover was evaluated for multiple agricultural operations including:

- Soil moisture monitoring and automatic irrigation
- Obstacle detection and navigation control
- Seed sowing operation
- Wireless monitoring through IoT communication
- Controlled water spraying operation

Performance observations such as operating time, sensor response, movement stability, and power consumption were recorded during field operation.

TABLE IV Field Performance Evaluation of Smart Agriculture Rover

Parameter	Observed Performance
Average Operating Time	4–5 Hours
Soil Moisture Detection	Stable
Obstacle Detection Range	2–80 cm
Irrigation Response	Automatic
Wireless Communication Range	~20–25 m
Average Power Consumption	~32 W
Rover Movement Stability	Good
Seed Sowing Operation	Uniform
Water Spraying Control	Controlled
Battery Backup Performance	Satisfactory

C. Observations During Practical Operation

During testing, the rover successfully performed automatic irrigation based on soil moisture conditions without requiring continuous human supervision. The ultrasonic sensor effectively detected nearby obstacles and prevented collision during movement.

The integrated seed sowing mechanism maintained relatively uniform seed dispensing intervals during forward motion. Wireless communication through the ESP32 module enabled real-time monitoring and remote operational control using a smartphone interface.

The lightweight structure and low power consumption of the rover improved maneuverability and operational efficiency for small agricultural applications. Reduced manual effort and lower operating cost were identified as major advantages during practical implementation.

D. Performance Benefits Observed

The field implementation demonstrated several practical advantages of the proposed system:

- Reduced manual labor requirement
- Lower water wastage through automatic irrigation
- Improved operational efficiency
- Reduced electrical power consumption
- Simplified field monitoring using IoT
- Compact and portable design

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- Low operational noise during movement

The integrated multitasking capability of the rover makes it suitable for small and medium-scale precision agriculture applications.

IX. REVIEW OF RELATED WORK

The application of automation in agriculture has increased significantly in recent years due to the growing demand for efficient farming techniques, reduced labor dependency, and improved resource management. However, modern smart farming research is gradually moving toward integrated robotic systems capable of performing multiple agricultural operations within a single platform.

Patel et al. (2023) introduced a smart irrigation model using Arduino-based control and soil moisture sensing techniques for automatic water management in agricultural fields. Their system successfully reduced unnecessary water usage and improved irrigation efficiency. However, the developed setup was stationary in nature and did not include mobility or multifunctional farming operations.

Kumar and Sharma (2024) designed an agricultural spraying robot intended for automatic pesticide application. The system reduced manual spraying effort and improved operator safety during chemical spraying activities.
Although the robot provided effective spraying capability, it lacked additional features such as seed sowing, field monitoring, and intelligent navigation.

Verma et al. (2024) developed a wireless agricultural monitoring platform integrating environmental sensors and IoT communication modules for real-time supervision of farming conditions. Their work demonstrated the importance of remote monitoring and sensor-based decision systems in precision agriculture. Nevertheless, the system was limited to environmental monitoring and did not support autonomous field movement or operational automation.

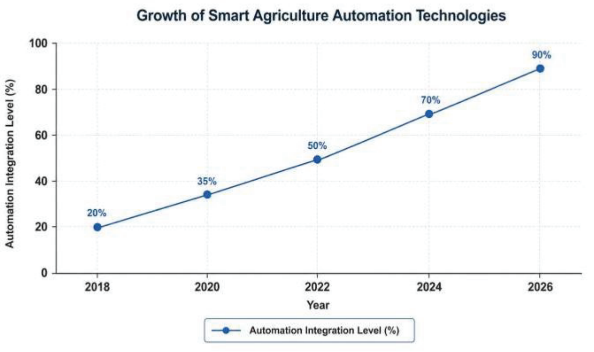

Figure 8 Growth of Smart Agricltuure Automation

A study published in IRJMETS (2025) discussed compact agricultural robotic systems developed for small-scale farming applications. The research emphasized low-cost automation using embedded controllers, DC motors, and sensor-assisted movement mechanisms. The study concluded that compact robotic systems can effectively reduce labor-intensive farming activities and improve operational efficiency in small agricultural fields.

The IEEE Smart Farming Initiative Report (2025) highlighted the increasing adoption of robotics, IoT communication, and intelligent sensing technologies in modern agricultural equipment. The report emphasized that future farming systems should combine automation, wireless monitoring, obstacle detection, and resource optimization to achieve higher productivity with reduced operational cost.

Most of the systems discussed in existing literature focus only on individual agricultural functions such as irrigation, monitoring, or spraying. In comparison, the proposed Smart Agriculture Rover combines multiple operations including irrigation control, pesticide spraying, seed sowing, obstacle detection, and IoT-based monitoring within a single integrated platform. The developed system is intended to provide an economical, flexible, and practical automation solution suitable for small and medium-scale farming environments.

X. FABRICATION CHALLENGES: RURAL ELECTRICAL ENGG. STUDENT PERSPECTIVE

During the development of the Smart Agriculture Rover, the project team encountered several practical and technical challenges related to fabrication, sensor integration, programming, and field testing. Most of these difficulties were associated with limited laboratory resources, component availability, and real-time synchronization of multiple agricultural operations. The challenges and corrective measures adopted during the project implementation are discussed below.

A. Component Procurement and Delivery Delays

Certain electronic components required for the rover such as ESP32 modules, ultrasonic sensors, motor drivers, relay modules, geared DC motors, and lithium-ion batteries were not readily available in nearby local markets. These components had to be purchased from online suppliers, which increased the overall development time due to delivery delays.

In some cases, replacement of damaged modules and faulty wiring components was necessary during testing, resulting in additional waiting periods and repeated hardware assembly.

B. Mechanical Fabrication and Structural Alignment

The fabrication of the rover chassis and wheel assembly required careful mechanical balancing to achieve smooth movement on uneven agricultural surfaces. Initial testing revealed vibration problems and unstable movement caused by improper wheel alignment and uneven weight distribution.

Additional support brackets and reinforced motor mounting arrangements were introduced to improve rover stability and load handling capability during irrigation and seed sowing operations

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C. Sensor Calibration and Circuit Integration

Integrating multiple sensors into a single control system created calibration and interfacing difficulties during implementation. Soil moisture sensor readings fluctuated because of varying soil conditions, while ultrasonic sensor measurements were occasionally affected by environmental interference.

Several trial-and-error calibration procedures were carried out to stabilize sensor readings. Software-level filtering and threshold optimization were later implemented to improve system reliability during field operation.

D. Programming and Synchronization Challenges

One of the major technical difficulties involved synchronization between rover movement, obstacle detection, irrigation control, and seed sowing operations. During initial programming stages, timing mismatches caused irregular movement and inconsistent seed dispensing.

The controller program was later redesigned using modular programming techniques and optimized timing control functions to improve multitasking coordination and operational stability.

E. Power Distribution and Battery Management Issues

Since the rover operated multiple electrical loads simultaneously, sudden current variation during motor startup and pump operation occasionally caused voltage fluctuation in the control circuit. This affected sensor readings and communication stability during testing.

To overcome this issue, voltage regulation circuits and proper power distribution arrangements were incorporated to ensure stable controller performance and improved battery utilization.

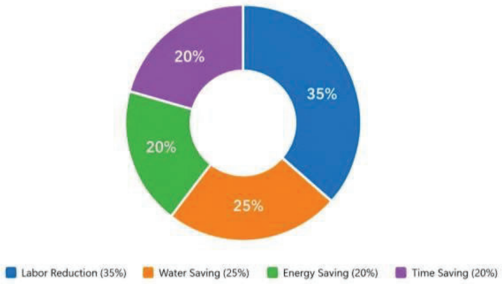

Figure 9 Efficiency Improvement using Smart Agriculture Rover

F. Wireless Communication and IoT Connectivity

Wireless communication through the ESP32 module initially experienced occasional signal interruption during outdoor testing due to network range limitations and environmental disturbances. Communication performance was improved through optimized Wi-Fi configuration and reduction of unnecessary background data transmission.

TABLE V Summary of Fabrication Challenges and Corrective Measures

Challenge	Impact on Project	Corrective Measure
Delay in electronic component delivery	Increased development duration	Online procurement and spare component arrangement
Chassis imbalance and vibration	Unstable rover movement	Reinforced frame and wheel alignment
Soil moisture sensor fluctuation	Inaccurate irrigation control	Sensor calibration and threshold adjustment
Ultrasonic sensing interference	Incorrect obstacle detection	Software filtering and repeated testing
Synchronization between subsystems	Irregular multitasking operation	Modular programming optimization
Voltage fluctuation during operation	Controller instability	Voltage regulation and power distribution
Wi-Fi signal interruption	Communication delay	ESP32 network optimization

XI. RECENT ADVANCEMENTS AND FUTURE SCOPE

The field of smart agriculture and agricultural robotics is rapidly advancing with the integration of IoT, Artificial Intelligence (AI), automation, and renewable energy technologies. Modern agricultural rovers are now capable of autonomous navigation, real-time crop monitoring, precision spraying, and smart irrigation systems.

Recent developments relevant to this project include:

i. IoT-Based Smart Farming:

Integration of ESP32 and cloud platforms enables real-time monitoring of soil moisture, temperature, humidity, and battery status through mobile applications.

ii. Solar-Powered Agricultural Systems:

Solar charging systems are being used to reduce dependency on grid electricity and improve energy efficiency in agricultural robots.

iii. AI and Computer Vision:

AI-based crop monitoring and weed detection systems using machine learning and camera modules are improving precision farming techniques.

iv. GPS and Autonomous Navigation:

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Modern agricultural rovers use GPS-based navigation and automatic path planning for efficient field operations.

v. Smart Irrigation Systems:

Advanced moisture sensing and automated irrigation technologies help conserve water and improve crop productivity.

XII. CONCLUSION

This project has documented the complete design, development, implementation, and testing of the Smart Agriculture Rover with Multi-Tasking Mechanism, developed as a major project for smart farming applications. The rover integrates automation, embedded systems, IoT communication, and intelligent sensing technologies to perform multiple agricultural operations efficiently. The major outcomes of the project are summarized as follows:

i. Automation of Agricultural Tasks: The rover successfully automated essential farming activities such as seed sowing, pesticide spraying, irrigation control, obstacle detection, and field monitoring, thereby reducing manual labor and improving operational efficiency.

ii. Smart Irrigation System: The soil moisture sensor-based irrigation system enabled automatic water control, reducing unnecessary water usage and supporting efficient water conservation practices in agriculture.

iii. Multi-Tasking Capability: The developed rover demonstrated the ability to perform multiple operations simultaneously, including movement, monitoring, spraying, and sensing, using a single integrated control system.

iv. Low-Cost Smart Farming Solution: The total prototype cost was maintained within an economical range of approximately ₹8,000–12,000, making the system affordable and suitable for small and medium-scale farmers.

v. Obstacle Detection and Safety: The ultrasonic sensor-based obstacle avoidance system improved navigation safety and prevented accidental collisions during rover movement in agricultural fields.

vi. Wireless Monitoring and IoT Integration: The implementation of Bluetooth/Wi-Fi communication enabled remote monitoring and control of the rover, supporting future IoT-based smart agriculture applications.

vii. Energy Efficient Operation: The rover operates using a rechargeable battery-powered electrical system, resulting in lower operating costs, reduced fuel dependency, and environmentally friendly operation.

viii. Practical Engineering Learning: The project provided hands-on experience in embedded systems, sensor interfacing, motor driver circuits, IoT communication, power electronics, automation, and robotic system integration.

ix. Scalability and Future Scope: The designed system can be further enhanced using GPS navigation, artificial intelligence, machine learning, solar charging systems, and autonomous path planning for advanced precision agriculture.

x. Social and Agricultural Impact: The project demonstrates that smart robotic systems can significantly support Indian farmers by reducing physical effort, improving productivity, conserving resources, and promoting modern precision farming techniques.

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