SMART AGRICULTURAL ROVER FOR WEED REMOVAL AND ENVIRONMENTAL MONITORING

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***Abstract*—Agriculture remains a cornerstone of developing economies, yet traditional farming practices continue to rely heavily on manual labor, incurring high operational costs and productivity losses. This paper presents the design and implementation of an IoT and Sensor-Based Smartphone-Operated Multipurpose Agricultural Robotic Vehicle (SARWR) capable of performing multiple farming operations—including grass cutting, seed sowing, soil moisture monitoring, and irrigation—within a single automated platform. The system utilizes an ESP32 microcontroller as the central processing unit, interfaced with soil moisture, temperature, humidity, and Light Dependent Resistor (LDR) sensors for real-time field monitoring. An L298N dual H-bridge motor driver controls the locomotion and task-specific DC motors, while a relay module manages the water pump. The robot is wirelessly controlled through a smartphone application via Bluetooth and Wi-Fi communication protocols. Solar panels provide a renewable energy source, making the system eco-friendly and energy-independent. The proposed system was tested under various field conditions, and results demonstrate significant reductions in manual labor, improved seed placement accuracy, and effective weed removal. The integration of IoT connectivity enables remote monitoring of field parameters through a cloud dashboard, supporting precision agriculture and sustainable farming practices.**

***Keywords*—IoT, ESP32, agricultural robot, soil moisture sensor, smartphone control, L298N motor driver, precision farming, solar energy, automation, seed sowing**.

I. INTRODUCTION

Agriculture is the backbone of many developing nations, employing a large percentage of the population and contributing substantially to national GDP. However, the sector faces mounting challenges: labor shortages, rising input costs, inconsistent crop management, and a lack of real-time monitoring of soil and environmental conditions. In rural areas, these challenges are compounded by limited access to advanced mechanized equipment, resulting in over-reliance on time-consuming manual operations for critical tasks such as seed sowing, weed removal, and irrigation management.

Recent advances in embedded systems, wireless communication, and the Internet of Things (IoT) have created new opportunities to modernize agricultural practices. Robotic systems capable of performing repetitive, precision-intensive tasks autonomously are being increasingly adopted in precision agriculture. Such systems reduce labor dependency, improve operational accuracy, and allow real-time remote monitoring—all of which contribute to enhanced crop yields and resource efficiency.

This paper presents the design and implementation of the IoT and Sensor-Based Smartphone-Operated Multipurpose Agricultural Robotic Vehicle (SARWR). The system consolidates several common farming operations into a single robotic platform. The ESP32 microcontroller serves as the brain of the system, communicating wirelessly with a user-operated smartphone to receive movement and task commands. Multiple sensors monitor soil moisture, temperature, humidity, and ambient light. An L298N motor driver controls vehicle movement and task actuators, while solar panels provide a sustainable power supply. The system is well-suited for small to medium-scale farms seeking affordable automation.

The key contributions of this work are: (1) a unified multi-task agricultural robot controlled entirely by smartphone; (2) integration of real-time IoT sensor monitoring with cloud connectivity; (3) solar-powered operation for environmental sustainability; and (4) experimental validation demonstrating effectiveness across multiple agricultural tasks.

II. RELATED WORK

Several prior works have explored automated systems for specific agricultural operations. Belgali et al. [1] developed an automatic seed sowing robot using a microcontroller, motor driver, and IoT-based mobile application control. Their robot achieved multi-directional movement and included a seed dispensing mechanism with fixed inter-seed intervals, demonstrating cost-effectiveness for rural deployment.

Preethi et al. [2] proposed an IoT-based seed sowing system in which wireless connectivity allowed farmers to remotely monitor and control the seeding process via smartphone or web platform. The system ensured uniform seed placement and reduced manual planting time. Real-time data collection supported improved resource management decisions.

Sandesh et al. [3] presented the AG-Robot, an automated sowing robot employing sensors, motors, and a microcontroller-based control unit for planting seeds at predetermined distances and depths. The study highlighted the potential for extending the robotic platform to additional functions such as soil monitoring and crop management.

Vimal et al. [4] designed an automated seed sowing robot with mechanisms for land leveling and irrigation support alongside seed placement. Their design emphasized cost-effectiveness and accessibility for small-scale farmers, achieving precise seed distribution and reduced physical effort.

Kulkarni et al. [5] introduced a solar-powered multipurpose agricultural robot employing IoT technology to automate ploughing, seed sowing, grass cutting, and water sprinkling in a single integrated system. Their work most closely aligns with the present system and underscores the importance of combining robotics, renewable energy, and IoT for sustainable agricultural automation.

While these works demonstrate the viability of agricultural robotics, most address single tasks or lack comprehensive sensor integration with real-time IoT cloud monitoring. The proposed SARWR addresses these gaps by integrating multi-task capability, multi-parameter sensing, solar power, and cloud connectivity in a single smartphone-controlled platform.

III. SYSTEM DESIGN AND ARCHITECTURE

A. System Overview

The SARWR is designed around the ESP32 microcontroller, which coordinates all inputs from sensors and outputs to actuators. The system architecture is shown in Fig. 1. Sensor data from soil moisture, temperature, humidity, and LDR sensors feeds into the ESP32 for real-time processing. Commands from a smartphone application arrive via Bluetooth or Wi-Fi. Based on received commands and sensor states, the ESP32 controls the L298N motor driver for locomotion, the cutting blade motor, the water pump relay, and the seed sowing motor.

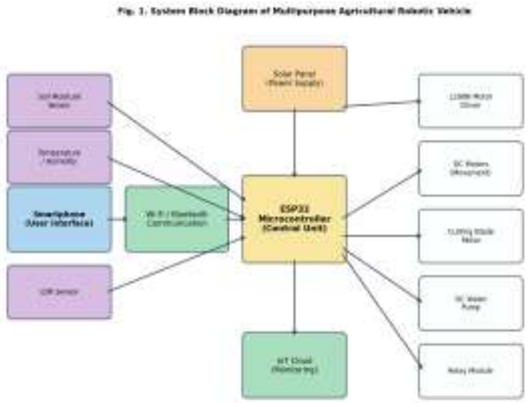

Fig. 1. System Block Diagram of SARWR

B. Operational Flowchart

The system operation follows a structured sequence as illustrated in Fig. 2. Upon power-up, the ESP32 initializes all peripheral sensors and waits for a smartphone command over the wireless link. Upon receiving a command, the appropriate actuator is activated. Concurrently, sensor readings are periodically collected and transmitted to the IoT cloud dashboard for remote monitoring.

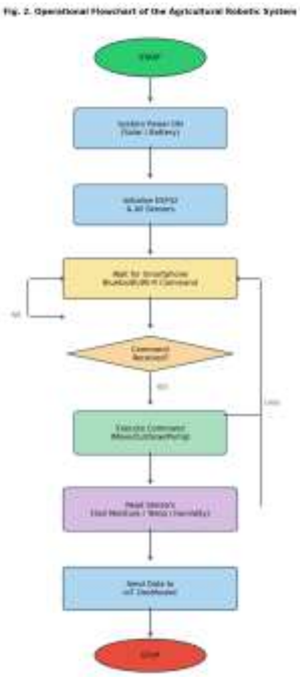

Fig. 2. Operational Flowchart of the Agricultural Robotic System

C. Hardware Architecture

Fig. 3 illustrates the hardware connection architecture of the system, showing how the ESP32 interfaces with input sensors on the left and output actuators on the right through the L298N motor driver module.

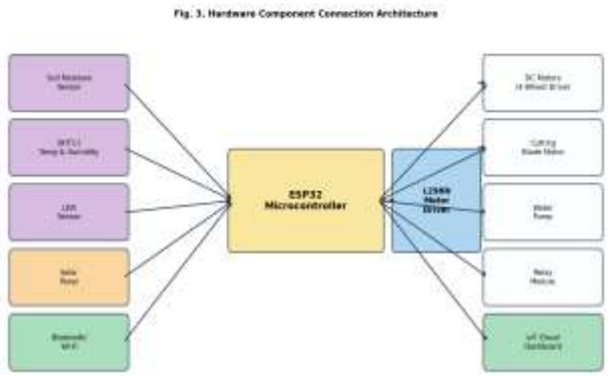

Fig. 3. Hardware Component Connection Architecture

IV. HARDWARE COMPONENTS

A. ESP32 Microcontroller

The ESP32, developed by Espressif Systems, is a dual-core Xtensa LX6 microcontroller operating at up to 240 MHz. It integrates Wi-Fi 802.11 b/g/n and Bluetooth v4.2 (Classic + BLE) capabilities, providing versatile wireless communication for IoT applications. With 520 KB of SRAM, up to 4 MB of external flash memory, 34 GPIO pins, 18 ADC channels, and support for UART, SPI, I2C, CAN, and I2S communication interfaces, the ESP32 is ideally suited as the central controller for the SARWR system. It processes sensor inputs, generates control signals for actuators, maintains wireless communication with the smartphone, and transmits data to the IoT cloud.

B. Soil Moisture Sensor

The soil moisture sensor measures the volumetric water content of the soil using two electrodes that detect the electrical resistance between them. As soil moisture increases, resistance decreases. The sensor output is read by the ESP32 ADC to generate a digital moisture level reading. In agriculture, accurate soil moisture data enables optimized irrigation scheduling, reducing water consumption while maintaining crop health [6].

C. Temperature and Humidity Sensor

A thermistor-based temperature sensor and capacitive humidity sensor (DHT series) measure ambient temperature and relative humidity. These parameters are critical for crop management decisions. The thermistor exhibits a negative temperature coefficient (NTC) characteristic, where resistance decreases with increasing temperature. Relative humidity is derived from capacitance changes in a polymer film sandwiched between two conductive plates, converted to a digital reading by the ESP32.

D. Light Dependent Resistor (LDR)

The LDR is a photoresistor whose resistance decreases with increasing incident light intensity. Fabricated from cadmium sulfide (CdS), the LDR allows the SARWR to detect ambient lighting conditions, supporting automatic operational mode switching between daylight and low-light scenarios. When light of sufficient frequency strikes the semiconductor, photons excite electrons into the conduction band, lowering resistance and increasing conductivity.

E. L298N Motor Driver Module

The L298N is a dual H-bridge motor driver IC that enables bidirectional control of two DC motors independently. Operating at motor supply voltages of 5 V to 35 V with a continuous output current of up to 2 A per channel (peak 3 A), the L298N is adequate for driving the SARWR's locomotion motors. PWM signals applied to the enable pins (ENA/ENB) regulate motor speed, while logic inputs (IN1–IN4) determine rotation direction. The truth table governing motor direction is summarized in Table I.

TABLE I. L298N MOTOR DIRECTION CONTROL TRUTH TABLE

IN1	IN2	Motor Action
LOW	LOW	Motor OFF
HIGH	LOW	Forward
LOW	HIGH	Backward
HIGH	HIGH	Motor OFF

F. Relay Module

A relay is an electromechanical switch that allows the low-voltage ESP32 output to control high-power circuits. When the ESP32 sends a HIGH signal to the relay coil via a transistor driver stage, the coil generates a magnetic field that closes the switch contacts, energizing the DC water pump. This isolation between control and power circuits ensures protection for the microcontroller.

G. DC Motors and Cutting Blade

Four DC motors rated at 12 V, 1500 RPM provide four-wheel drive locomotion for the robotic vehicle. DC motors operate on the principle of electromagnetic interaction between current-carrying armature windings and permanent stator magnets, converting electrical energy to rotational motion. The cutting blade mechanism employs a high-speed DC motor driving a stainless steel or hardened carbon steel blade, rotating at high speed to sever unwanted weeds and grass. The blade is guarded by a protective housing to prevent damage to adjacent components.

H. DC Water Pump

A positive displacement DC pump moves water from an onboard reservoir to crop rows for irrigation. Controlled through the relay module, the pump is activated when the soil moisture sensor readings fall below a predefined threshold or when the operator sends the pump command via the smartphone interface.

I. Solar Panel

Solar panels convert incident solar irradiance into electrical energy via the photovoltaic effect, providing a renewable power source for the robotic system. The panels charge an onboard battery bank, which in turn powers the ESP32, sensors, and actuators. Solar integration reduces dependency on conventional power grids and lowers the operational carbon footprint of the system.

V. SOFTWARE IMPLEMENTATION

A. Development Environment

The Arduino IDE (Integrated Development Environment) with ESP32 board support was used for firmware development. The IDE provides a C/C++ programming environment with a rich library ecosystem supporting sensor interfacing, motor control, Bluetooth communication, and Wi-Fi connectivity. The SoftwareSerial library enables Bluetooth communication with the HC-05 or ESP32 integrated Bluetooth, while standard GPIO functions handle sensor readings and actuator control.

B. Command Interpretation Logic

The firmware continuously polls the Bluetooth/Wi-Fi communication buffer for incoming commands. Table II summarizes the command set implemented in the SARWR firmware. Upon receiving a valid command character, the appropriate function is invoked: movement functions configure the IN1–IN4 pins on the L298N motor driver, while task functions toggle the grass cutter and seed sowing motors via GPIO, or activate the pump relay.

TABLE II. SMARTPHONE COMMAND SET FOR SARWR

Command	Character	Function
'F'	Forward	Move Forward
'B'	Backward	Move Backward
'L'	Left	Turn Left
'R'	Right	Turn Right
'S'	Stop	Stop Robot
'G'	Grass ON	Start Cutter
'g'	Grass OFF	Stop Cutter
'W'	Sow ON	Start Seeding
'w'	Sow OFF	Stop Seeding

C. Sensor Monitoring Loop

In parallel with command handling, the firmware reads the soil moisture sensor at 200 ms intervals using analogRead() on the ADC pin. The acquired value is transmitted via the serial monitor for debugging and simultaneously forwarded to the IoT cloud platform (e.g., ThingSpeak or Firebase) via the ESP32's built-in Wi-Fi. This enables farmers to view real-time field data on a web dashboard or mobile application without requiring physical presence at the field.

VI. RESULTS AND DISCUSSION

A. System Testing

The SARWR prototype was assembled and tested across multiple operational scenarios in a simulated agricultural field environment. The ESP32 successfully established Bluetooth communication with the controlling smartphone within a range of approximately 10–15 meters under open-field conditions, and Wi-Fi connectivity extended this to approximately 30–50 meters within network coverage.

B. Locomotion Performance

The four-wheel drive system achieved smooth and responsive directional control. Commands transmitted from the smartphone were processed with a latency below 50 ms. The robot successfully navigated forward, backward, left, and right on flat surfaces, with the L298N effectively regulating motor speed through PWM signals. No motor stall or thermal cutoff events were observed during testing.

C. Task Execution

The grass cutting mechanism effectively removed small weeds and grass in the test area. The high-speed blade motor provided sufficient torque for cutting vegetation up to approximately 5 mm in diameter. The seed sowing mechanism dispensed seeds at regular intervals as the robot traversed the test field, achieving reasonably uniform seed spacing. The water pump successfully delivered irrigation water upon command activation.

D. Sensor Performance

Soil moisture readings were stable and consistent. Representative sensor output values are summarized in Table III, illustrating the system's ability to distinguish between dry, moderately moist, and wet soil conditions.

TABLE III. SOIL MOISTURE SENSOR OUTPUT VS. SOIL CONDITION

Soil Condition	ADC Value (0–1023)	Status
Dry	800 – 1023	Irrigation Required
Moderate	400 – 799	Optimal
Wet	0 – 399	Excess Moisture

E. Performance Comparison

Table IV presents a comparative analysis of the proposed SARWR system against representative existing approaches documented in the literature. The SARWR demonstrates a broader feature set than single-task systems, incorporating

IoT connectivity and solar energy features that are absent from many comparable platforms.

TABLE IV. COMPARATIVE ANALYSIS OF AGRICULTURAL ROBOTIC SYSTEMS

Feature	[1]	[2]	[3]	[4]	[5]	SARWR
Seed Sowing	Yes	Yes	Yes	Yes	Yes	Yes
Weed Cutting	Yes	No	No	No	Yes	Yes
Soil Sensor	No	Yes	No	No	No	Yes
IoT Monitoring	No	Yes	No	No	Yes	Yes
Solar Power	No	No	No	No	Yes	Yes
Multi-task	No	No	No	No	Yes	Yes

VII. ADVANTAGES AND APPLICATIONS

A. Advantages

- Reduces manual labor by automating repetitive farming tasks such as weeding, seed sowing, and irrigation.
- Consolidates multiple farming operations into a single robotic platform, improving cost-effectiveness.
- Smartphone-based wireless control provides operational convenience and accessibility.
- Solar power integration ensures environmental sustainability and energy independence.
- Real-time IoT sensor monitoring supports data-driven precision agriculture decisions.
- Scalable and adaptable to small and medium-scale farms without significant infrastructure investment.

B. Applications

- Automated weed and grass removal in crop fields.
- Precision seed sowing for improved germination uniformity.
- Smart irrigation management driven by real-time soil moisture data.
- Field monitoring and environmental data logging for research and decision support.
- Educational and research platforms for studying agricultural robotics and IoT systems.

VIII. CONCLUSION

This paper has presented the design, implementation, and experimental evaluation of the IoT and Sensor-Based Smartphone-Operated Multipurpose Agricultural Robotic Vehicle (SARWR). The system successfully integrates an ESP32 microcontroller, multi-parameter environmental sensors, an L298N dual H-bridge motor driver, and solar power generation into a single unified platform capable of performing grass cutting, seed sowing, soil moisture monitoring, and irrigation. Wireless Bluetooth and Wi-Fi communication enables seamless smartphone-based remote control with low latency, while IoT cloud connectivity provides real-time field data to farmers irrespective of their physical location.

Experimental results confirm the effectiveness of the system across all implemented task modes, with consistent sensor readings and reliable actuator response. The comparative analysis demonstrates that the SARWR offers a broader and more integrated feature set than comparable systems reported in the literature. Future work will focus on incorporating GPS-based autonomous navigation, computer vision for disease and pest detection, expanded sensor suites (e.g., NPK soil sensors), and machine learning-based crop health analytics to further advance the system toward a fully autonomous precision agriculture solution.

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