

Solar-Powered AgriBot for Precision Farming: Ploughing, Seeding, and Irrigation in Rural Agriculture

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ABSTRACT

The agricultural sector plays a vital role in the economic development of many countries, particularly in rural regions where farming serves as the primary source of livelihood. Modern agriculture faces challenges including labor shortages, increasing operational costs, inefficient resource utilization, and dependency on traditional farming practices. This paper presents a Solar-Powered AgriBot for Precision Farming capable of performing ploughing, seed sowing, irrigation, and environmental monitoring with minimal human intervention. The system is built around an ESP32 microcontroller integrated with soil moisture, temperature, and humidity sensors, a solar-powered battery management system, geared DC motors, a ploughing mechanism, a seed dispensing unit, and a water sprinkler system. Through IoT connectivity, farmers can remotely monitor environmental parameters and control the robot using an Android application. Experimental results confirm that the AgriBot successfully performs automated ploughing, uniform seed sowing, intelligent irrigation, and real-time environmental monitoring. The proposed system offers a cost-effective, environmentally friendly, and scalable solution for smart agriculture.

Keywords: Solar-Powered AgriBot, Precision Farming, ESP32, IoT, Soil Moisture Sensor, DHT11, Seed Dispensing,

Smart Agriculture, Renewable Energy, Automated Irrigation.

1. INTRODUCTION

Agriculture is the backbone of India and many developing economies, contributing significantly to food security, employment generation, and rural livelihoods. However, modern agriculture faces mounting pressures due to rising labor costs, declining availability of skilled agricultural workers, unpredictable climatic conditions, and inefficient resource utilization. Traditional farming methods rely heavily on manual labor for ploughing, sowing seeds, watering crops, and monitoring field conditions — activities that are time-consuming, labor-intensive, and often result in poor resource management.

Recent advancements in embedded systems, wireless communication, robotics, and Internet of Things (IoT) technologies have created unprecedented opportunities to automate agricultural processes and improve farming efficiency. Precision farming has emerged as an innovative approach that utilizes sensors, automated machines, and intelligent decision-making systems to optimize agricultural operations by applying resources only when and where necessary.

The proposed Solar-Powered AgriBot integrates automation and renewable energy technologies to perform multiple farming

operations on a single robotic platform. An ESP32 microcontroller serves as the central control unit responsible for acquiring sensor data, controlling robot movement, operating agricultural mechanisms, and facilitating wireless communication through an Android application. The robot autonomously performs ploughing, seed dispensing, and irrigation based on real-time soil moisture and environmental data.

The motivation behind this development stems from the need to provide farmers with an affordable, intelligent, and energy-efficient farming solution. By combining solar energy with IoT-enabled automation, the proposed system enables precision agriculture while minimizing environmental impact and operational cost. The system is particularly targeted at small and medium-scale farmers in rural India who cannot afford expensive commercial agricultural machinery.

2. LITERATURE SURVEY

Kumar et al. [1] developed a solar-powered multipurpose agriculture robot for ploughing, seed drilling, sowing, and irrigation with Wi-Fi/Bluetooth-based remote control and cloud logging, demonstrating that solar energy and IoT sensing can be combined for off-grid rural farming applications.

An IoT-based solar-powered Agribot using Arduino was proposed [2] to perform automatic ploughing, seed dispensing, and water spraying while uploading temperature, humidity, and soil moisture data to an IoT application for remote farmer monitoring.

Malode and Magadum [3] introduced a smart IoT-based precision farming robot with AI-driven irrigation and seed sowing. Their system used soil moisture, temperature, humidity, and weather forecast data to optimize watering schedules using decision tree and random forest machine learning algorithms, highlighting the importance of intelligent irrigation control.

A recent multipurpose agricultural robot designed using ESP32 microcontroller, motor drivers, DC motors, and a water pump [4] validated the ESP32 as a suitable controller for smart agricultural robots performing simultaneous soil ploughing, seeding, and water spraying.

Nishant Raj et al. [5] designed a solar-operated multipurpose agricultural robot for soil preparation and farming automation, focusing on sustainability and small-farmer accessibility through solar-assisted operation. Vasudha Hegde et al. [6] developed a solar-operated smart multifunctional Agribot capable of ploughing, seeding, grass cutting, and irrigation using Bluetooth-based mobile control, demonstrating the viability of multifunctional robotic platforms.

Studies on IoT-based smart agricultural watering robots using fuzzy-PID control [7] showed how automatic irrigation can reduce water wastage and improve watering accuracy based on real-time sensor feedback. A GPS-guided IoT-integrated autonomous Agribot study [8] emphasized that solar-powered agricultural automation reduces fossil fuel dependency and supports environmentally friendly farming.

A multifunctional ESP32-based agricultural robot [9] using a 12V battery supported by a 5W solar panel reported reduced manual labor, uniform seed distribution, and efficient water usage — results highly consistent with the objectives of the proposed system. Collectively, the surveyed literature confirms that combining ESP32 microcontrollers, solar energy, IoT connectivity, and multi-mechanism agricultural robots represents a mature and validated approach to precision farming automation.

3. EXISTING SYSTEM

Traditional agricultural practices primarily rely on manual labor and conventional farming equipment such as tractors, manual seed drills, and irrigation pumps that require

continuous human supervision and significant operational costs. These methods are time-consuming, labor-intensive, and inefficient in utilizing resources such as water, seeds, and energy. In many rural areas, farmers face challenges due to labor shortages, increasing fuel costs, and lack of real-time information about soil and environmental conditions.

Several existing agricultural automation systems focus on performing only a single task such as irrigation, ploughing, or seed sowing. Many existing robots depend on external power sources or fossil fuels, increasing operating expenses and environmental impact. Furthermore, conventional systems often lack integrated IoT monitoring capabilities, making remote supervision of field conditions difficult. The absence of renewable energy integration, real-time sensor-based decision making, and multifunctional automation limits the effectiveness of existing systems in modern precision agriculture.

TABLE I: Comparison of Existing vs. Proposed Systems

Feature	Manual Farming	Existing Robot	Proposed Agribot
Energy Source	Fossil Fuel	Electric Grid	Solar Renewable
IoT Monitoring	No	Partial	Yes (Real-time)
Multi-function	No	Single task	Plough+Seed+Irrigate
Auto Irrigation	No	Manual	Sensor-triggered
Remote Control	No	Wired	Wi-Fi Android App
Labor Dependency	High	Medium	Minimal
Cost (Est.)	High (labor)	High	Low (≈₹5,000)

Table I illustrates that the proposed Agribot outperforms conventional manual farming and single-function existing robots across all key parameters including energy source, IoT monitoring capability, multi-function

operation, automation, and cost. The proposed system directly addresses the identified gaps by integrating solar power, wireless connectivity, and multi-mechanism automation into a single low-cost agricultural platform.

4. PROPOSED METHODOLOGY

A. System Architecture

The proposed Solar-Powered Agribot for Precision Farming is an intelligent agricultural robot designed to automate major farming activities using renewable energy and IoT technologies. The system consists of a solar panel, rechargeable battery, ESP32 microcontroller, soil moisture sensor, temperature sensor, humidity sensor, IoT communication module, ploughing mechanism, seed dispensing mechanism, water sprinkler system, and geared DC motors for robot movement.

B. Block Diagram

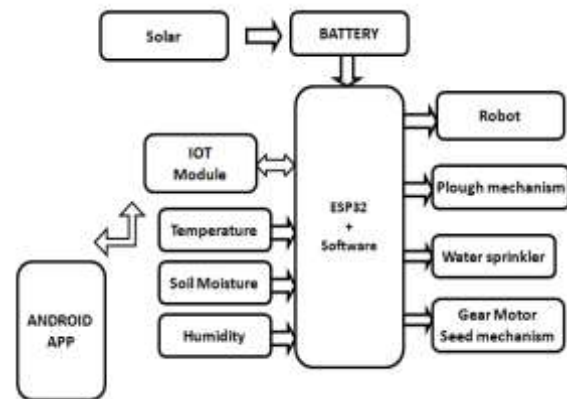


Figure 1: Proposed System Block Diagram

The block diagram (Fig. 1) illustrates the architecture of the proposed Solar-Powered Agribot. Solar energy is harvested through the solar panel and stored in a rechargeable battery, which supplies power to the ESP32-based control unit. The ESP32 receives input data from soil moisture, temperature, and humidity sensors and communicates with the Android application through the IoT module.

Based on sensed environmental conditions, the controller automatically activates the ploughing mechanism, seed dispensing unit, and water sprinkler system. The robot movement is controlled through geared DC motors for autonomous or remote operation.

Built-in Wi-Fi	IoT / Android App	Wireless communication
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C. Hardware Components

TABLE II: Hardware Components and Specifications

Component	Specification
ESP32 Microcontroller	Dual-core 240 MHz, Wi-Fi + BT
Solar Panel	5W, 6V/830mA
Rechargeable Battery	12V, 7Ah Li-ion
Soil Moisture Sensor	Capacitive, 0–100% range
DHT11 Sensor	Temp: 0–50°C, Humidity: 20–90%
L298N Motor Driver	Dual H-bridge, 2A per channel
DC Geared Motors	12V, 100 RPM
Water Pump	12V submersible, 3L/min
Seed Dispenser Motor	Servo motor, 0–180°

D. ESP32 Pin Configuration

TABLE III: ESP32 GPIO Pin Description

GPIO Pin	Connected Component	Function
GPIO 34	Soil Moisture Sensor	Analog soil moisture input
GPIO 4	DHT11 Sensor	Temp & humidity digital input
GPIO 18	L298N Motor Driver	Left motor control
GPIO 19	L298N Motor Driver	Left motor direction
GPIO 21	L298N Motor Driver	Right motor control
GPIO 22	L298N Motor Driver	Right motor direction
GPIO 23	Seed Dispenser Servo	Seed dispensing control
GPIO 25	Relay (Water Pump)	Irrigation activation
GPIO 26	Ploughing Motor	Ploughing mechanism

E. Working Principle

The operation begins when solar energy is captured and stored in the rechargeable battery. After power-up, the ESP32 initializes all connected devices and continuously acquires data from the soil moisture, temperature, and humidity sensors. Collected sensor information is processed and transmitted to the Android application through Wi-Fi-based IoT communication, enabling farmers to observe real-time field conditions on their smartphones.

When the robot enters the agricultural field, the ploughing mechanism activates first to prepare the soil. As the robot moves forward, the ploughing blades loosen and cultivate the soil. Once ploughing is completed, the seed dispensing servo motor releases seeds at regular intervals to ensure uniform sowing. The soil moisture sensor continuously monitors water content; when the level falls below the predefined threshold (ADC value > 500), the ESP32 activates the water pump and sprinkler system. When sufficient moisture is achieved, irrigation is automatically switched OFF to prevent water wastage.

The system supports both autonomous and remote-controlled operation modes. In autonomous mode, all decisions are sensor-driven. In remote mode, the farmer sends directional commands (Forward: 'A', Backward: 'B', Right: 'C', Left: 'D', Stop: 'E') through the Android application to navigate the robot. The pump and seed dispenser can also be manually activated via commands 'F'/'G' and 'H'/'I' respectively.

F. Software Implementation

The firmware is developed in Arduino C++ using the ESP8266WiFi, Servo, and DHT libraries. The ESP32 creates a Wi-Fi access point with SSID 'project123' and listens for client connections on port 80. Upon receiving a character command from the

Android client, the controller executes the corresponding action through conditional parsing. The DHT11 sensor is read every 1000 ms to provide temperature and humidity updates, while the soil moisture ADC is sampled continuously. A dry threshold of 500 ADC units triggers automatic irrigation, ensuring timely and efficient water application.

5. RESULTS AND DISCUSSIONS

A. Hardware Prototype Result

The Solar-Powered Agribot hardware prototype was successfully developed and tested under field-like conditions. The robot consists of a solar panel mounted on the top surface, rechargeable battery, ESP32 controller, geared DC motors, ploughing blades at the front, seed dispensing servo mechanism, water sprinkler system, and IoT communication module. The solar panel continuously charges the onboard battery, enabling sustainable autonomous operation in agricultural fields without dependence on external power sources.



Figure 2: Solar-Powered Agribot Hardware Prototype Result Description

The ploughing attachment mounted at the front effectively prepares the soil as the robot moves forward. The integrated seed dispensing and irrigation mechanisms allow the robot to perform multiple agricultural

operations simultaneously. The prototype demonstrates successful development of an autonomous solar-powered farming robot capable of reducing manual labor and improving agricultural efficiency.

B. IoT Monitoring and Control Result

Real-time monitoring and control were validated through an Android IoT application connected to the ESP32 via Wi-Fi. The terminal interface displays live sensor readings including soil moisture status, temperature, and humidity values collected from the field. The messages 'Soil DRY' and 'Soil WET' confirm successful operation of the automatic irrigation decision mechanism based on the ADC threshold.

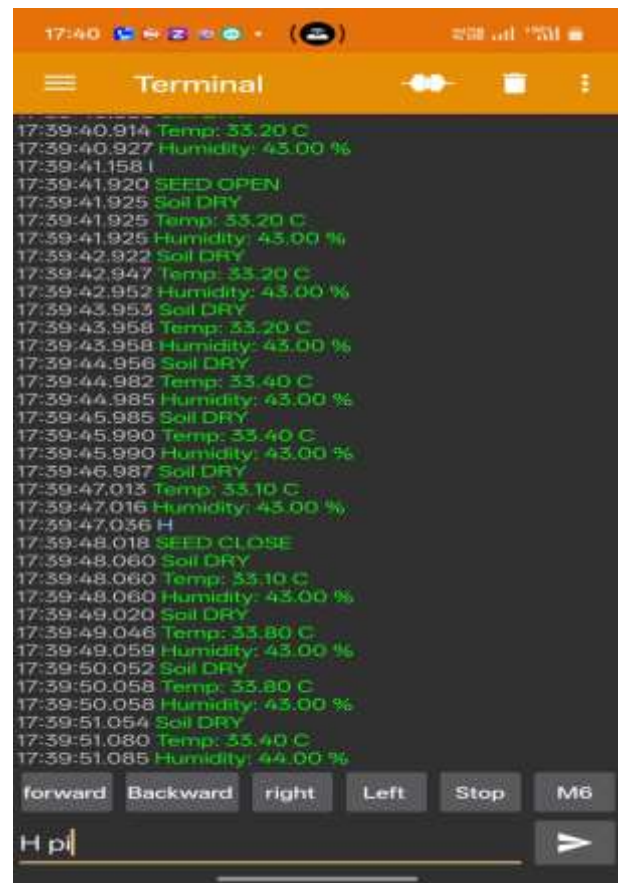


Figure 3: IoT Monitoring and Robot Control Result Description

The messages 'SEED OPEN' and 'SEED CLOSE' confirm successful operation of the automatic seed dispensing mechanism. The

application also provides directional control buttons enabling remote navigation of the robot. Temperature values consistently recorded around 33°C and humidity levels around 43–44% were continuously transmitted from the field to the mobile device, confirming successful wireless communication and real-time environmental monitoring.

TABLE IV: Sensor Test Results and System Response

Parameter	Sensor	Range	Observed Value	Action Triggered
Soil Moisture	Capacitive	0–1023 ADC	612 (Dry)	Irrigation ON
Soil Moisture	Capacitive	0–1023 ADC	320 (Wet)	Irrigation OFF
Temperature	DHT11	0–50 °C	33 °C	Data Logged
Humidity	DHT11	20–90 %	43–44 %	Data Logged
Battery Voltage	ADC Monitor	11–14 V	12.4 V	Normal Operation

C. Performance Analysis

Table IV summarizes observed sensor values and the corresponding system actions during testing. When the soil moisture ADC reading was 612 (dry condition), irrigation was automatically activated, confirming correct threshold-based decision making. When the reading was 320 (wet condition), irrigation was deactivated, preventing water wastage. The DHT11 sensor consistently logged temperature at 33°C and humidity at 43–44%, with data successfully transmitted to the Android application through the IoT platform.

The system demonstrated reliable Wi-Fi connectivity with the ESP32 maintaining a stable connection to the Android client throughout testing. The ploughing mechanism operated continuously during forward movement, providing effective soil

preparation. Seed dispensing via the servo motor produced uniform seed placement at configurable intervals. The solar panel provided adequate charging current to sustain battery voltage at 12.4V during daytime operation, confirming the viability of solar-powered autonomous farming.

Overall, the proposed Agribot achieved its design objectives of automated ploughing, precision seed sowing, sensor-triggered irrigation, real-time IoT monitoring, and remote control — all within an estimated cost of approximately ₹5,000, making it substantially more affordable than comparable commercial agricultural automation systems.

6. CONCLUSION

The proposed Solar-Powered Agribot for Precision Farming successfully demonstrates the integration of renewable energy, IoT technology, embedded systems, and agricultural automation into a single intelligent farming platform. The system utilizes a solar panel and rechargeable battery to provide a sustainable power source for field operations, making it suitable for rural and remote agricultural environments. The ESP32 microcontroller effectively coordinates the operation of soil moisture, temperature, and humidity sensors, while controlling the ploughing mechanism, seed dispensing unit, irrigation system, and robot movement.

Experimental results confirm that the Agribot can perform automatic ploughing, uniform seed sowing, intelligent irrigation, and real-time environmental monitoring successfully. The soil moisture sensor ensures efficient water utilization by activating irrigation only when required, reducing water wastage. The solar-powered operation reduces dependence on conventional energy sources and lowers operational costs. Remote monitoring and control through the Android application enables efficient farm management with minimal human intervention.

The proposed system improves agricultural productivity, minimizes labor requirements, conserves natural resources, and supports precision farming practices. The Agribot offers a cost-effective (\approx ₹5,000), eco-friendly, and scalable solution for modern smart agriculture, with significant potential for enhancing sustainable farming in rural communities. Future work will focus on adding GPS-guided autonomous navigation, machine learning-based crop health monitoring, and multi-field operation capabilities.

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