

Solar Powered Multipurpose Agriculture Robot Using ESP32 Microcontroller

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ABSTRACT : Agriculture plays a vital role in food production and the economy, especially in developing nations like India. Traditional farming methods demand excessive manual labor, time, and resources. This paper presents the design, development, and experimental testing of a Solar Powered Multipurpose Agriculture Robot (SPMAR) aimed at automating key farming operations.

The robot is built around an ESP32 microcontroller and powered by renewable solar energy. It integrates DC motors, an L298N dual H-bridge motor driver, a seed hopper, a mini submersible water pump, and a mechanical ploughing unit. The system operates in two modes — Automatic Mode (sensor-driven) and Manual Mode (Bluetooth/Wi-Fi remote control via a mobile application). Sensor data is transmitted to the ThingSpeak IoT cloud platform for real-time monitoring.

Experimental results confirm that the robot successfully performs ploughing, seed sowing, drilling, and irrigation. The irrigation system achieved a 20% increase in soil moisture within 30 minutes and covered approximately 500 m² per water-tank cycle. Seed placement efficiency was 85–90%. Autonomous navigation achieved a 90% obstacle avoidance success rate. Overall, the system demonstrated a 23% reduction in water usage and a 3–4× increase in effective labor productivity compared to conventional methods.

Keywords: Agricultural robot, ESP32, solar energy, IoT, precision farming, autonomous navigation, seed sowing, irrigation, ploughing, smart agriculture.

1. INTRODUCTION

Agriculture is the backbone of the Indian economy, with over 58% of rural household income

dependent on farming. However, rising labor shortages due to rural-to-urban migration, unpredictable climatic conditions, and the inefficiencies of manual farming have created an urgent need for intelligent, automated agricultural solutions.

Recent advances in embedded systems, Internet of Things (IoT), and renewable energy have opened new possibilities for affordable and scalable farm automation. Robotic platforms capable of performing multiple agricultural tasks autonomously can address labor shortages, improve resource efficiency, and reduce operational costs for small and marginal farmers.

This paper presents a Solar Powered Multipurpose Agriculture Robot (SPMAR) designed to automate the four primary field operations: ploughing, seed drilling, seed sowing, and irrigation. The system employs an ESP32 microcontroller as its central control unit, exploits built-in Wi-Fi and Bluetooth for remote operation and cloud data logging, and harvests solar energy for off-grid suitability. The primary objectives of the project are:

- To design and develop a solar-powered robot capable of performing ploughing, seed drilling, seed sowing, and irrigation autonomously.
- To integrate real-time environmental monitoring using DHT11 (temperature/humidity) and soil moisture sensors.
- To enable remote monitoring by transmitting sensor data to the ThingSpeak IoT cloud platform via Wi-Fi.
- To implement dual operation modes: Automatic Mode (sensor-driven autonomous control) and Manual Mode (mobile app via Bluetooth).
- To demonstrate a cost-effective and eco-friendly alternative to conventional manually operated farm machinery

2. LITERATURE SURVEY

Shamshiri et al. [1] provided a comprehensive review of robotics in digital farming, showing that agricultural robots reduce labor dependency and improve efficiency across seeding, weeding, spraying, and harvesting tasks. The authors concluded that human-robot collaboration is the future of smart agriculture.

Droukas et al. [2] surveyed robotic harvesting systems, comparing arms, computer-vision systems, and end-effectors, noting the need for improved speed and adaptability.

Rajendran et al. [3] focused on selective harvesting, demonstrating that AI-driven fruit-maturity detection can reduce waste and improve quality

Ahn et al. [5] reviewed perception methods for horticultural robots, highlighting that accurate sensing is critical to operational success.

3. System Components and Hardware

3.1 ESP32 Microcontroller

The ESP32 (Espressif Systems) is a low-cost, low-power System-on-Chip (SoC) selected as the central control unit due to its dual-core Xtensa LX6 processor (160/240 MHz), 520 KB SRAM, built-in 802.11 b/g/n Wi-Fi, Bluetooth Classic 4.2 + BLE, 34 programmable GPIO pins, and a 12-bit 18-channel ADC. Unlike single-core alternatives such as Arduino Uno, the ESP32's dual-core architecture allows one core to manage real-time motor control and sensor acquisition while the other handles Wi-Fi communication and cloud data uploads, with no lag in either function. Table 1 summarizes key specifications.

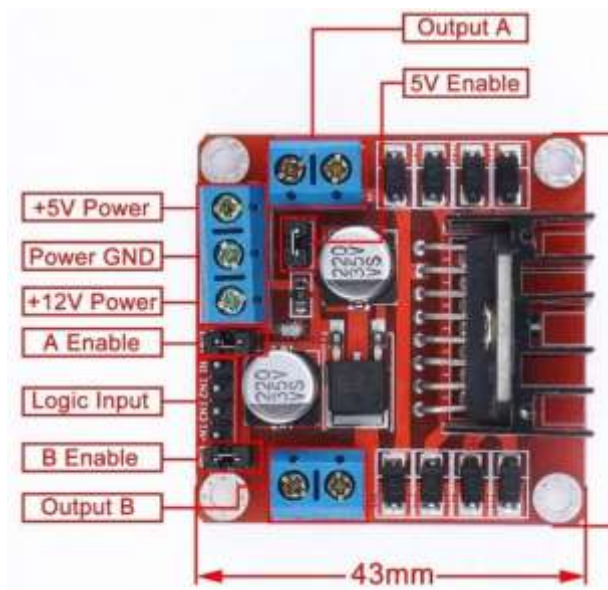


Parameter	Specification	Benefit
CPU	Dual-core Xtensa LX6, 160/240 MHz	Simultaneous multi-task execution
RAM	520 KB SRAM	Fast data storage
Flash	4 MB (external)	Program code storage
Wi-Fi	802.11 b/g/n (2.4 GHz)	Cloud upload to ThingSpeak
Bluetooth	Classic BT 4.2 + BLE	Mobile app control
GPIO	34 programmable pins	Motor, sensor, relay control
ADC	12-bit, 18 channels	Accurate analog readings

3.2 Motor Driver: L298N Dual H-Bridge

The L298N motor driver IC was selected to control the DC motors. Its dual H-bridge configuration allows independent control of two DC motors — enabling both direction reversal (by flipping current polarity) and variable speed control (via PWM signals from the ESP32). Key specifications include a motor voltage range of 5–35 V, 2 A per channel current capacity, and an onboard 5 V regulator for logic supply when using a 12 V battery.

Table 1. ESP32 Microcontroller Specifications



3.3 Solar Panel and Power System

A solar panel is mounted on the chassis to convert sunlight into electrical energy via the photovoltaic effect. A charge controller regulates the harvested energy, which is stored in a 12 V rechargeable battery. The battery supplies all subsystems: DC drive motors, the L298N motor driver, the ESP32, the water pump, and sensors. Solar powering makes the robot independent of grid electricity, making it particularly suitable for remote and rural agricultural areas.



3.4 DC Motors

Four DC gear motors (gear ratio approximately 1:48) drive the four-wheel chassis, providing adequate torque for movement across soft agricultural soil. Additional DC motors are mechanically coupled to the ploughing, drilling, and seeding implement assemblies.



3.5 Water Pump

A 3–6 V mini submersible water pump, controlled through a 5 V relay module connected to a GPIO pin of the ESP32, supplies the irrigation module. The pump draws water from an onboard reservoir and delivers it to the field via a nozzle or drip pipe



3.6 Seed Hopper

The seed hopper is a storage container that feeds seeds continuously to the seed-metering mechanism.



4. System Design

4.1 Overall Architecture

The system follows a hierarchical control architecture. The solar panel feeds a charge controller and battery. A regulated power supply unit distributes power to all subsystems. The ESP32 acts as the master

controller, receiving sensor inputs and issuing commands to four independent motor driver (L298N) modules that respectively drive: (i) the robot locomotion motors, (ii) the ploughing motor, (iii) the drilling and seeding motor, and (iv) the water pump relay. Wireless communication operates over both Bluetooth (mobile app, manual mode) and Wi-Fi (ThingSpeak cloud, monitoring).

4.2 Hardware Design

The hardware integrates the following sensor-to-actuator pathways:

- Soil Moisture Sensor → Analog GPIO pin → ESP32 ADC → Irrigation control logic → Relay → Water Pump.
- DHT11 Temperature/Humidity Sensor → Digital GPIO → ESP32 → ThingSpeak fields 1 & 2.
- HC-SR04 Ultrasonic Sensor → Digital trigger/echo GPIO → ESP32 → Obstacle avoidance logic → Drive motors.
- Mobile App (Bluetooth) → ESP32 Serial Bluetooth → Command parser → All actuator systems.

4.3 Mechanical Design

The chassis is fabricated from lightweight aluminium for a high strength-to-weight ratio, corrosion resistance, and ease of machining. Key dimensions are: length 600 mm, width 400 mm, height 620 mm. The wheelbase is 500 mm, the main wheel diameter is 150 mm, and front caster offset is 75 mm. A solar panel (600 mm × 350 mm) is mounted 250 mm above the base plate. Two seed hoppers are spaced 150 mm apart with a hopper outlet diameter of 20 mm. The design prioritizes structural rigidity through reinforced corners and cross-bracing, and weatherproofing via seals around sensitive electronic compartments.

4.4 Software Architecture

The firmware is developed in C++ using the Arduino IDE (v2.x) with the ESP32 board support package. The code is modular, comprising:

- Sensor Data Acquisition Module: reads soil moisture, temperature/humidity, and ultrasonic distance at each loop iteration.
- Motor Control Module: sends PWM signals (0–255, 8-bit resolution) to the L298N drivers; normal operation speed is 150 (≈59% duty cycle); a PID controller corrects straight-line drift using encoder feedback.

- Irrigation Control Module: activates the water pump relay when soil moisture falls below a configurable threshold.
- Communication Module: uploads sensor fields to ThingSpeak via HTTP GET every 15 seconds over Wi-Fi; receives single-character ASCII commands (F/B/L/R/S/P/D/W) from the Android app over Bluetooth Serial.
- Autonomous Navigation Logic: row-by-row coverage with U-turns at row ends; field dimensions are configured in firmware; future versions will integrate GPS-RTK for centimeter-level accuracy.

5. Testing and Results

5.1 Irrigation Performance

The water pump was activated automatically whenever the soil moisture sensor reading dropped below a predefined threshold. When triggered, the system raised soil moisture by an average of 20% within 30 minutes. A single water-tank load covered approximately 500 m² without refill, demonstrating the adequacy of the onboard reservoir for small plot coverage.

5.2 Autonomous Navigation

The robot was tested across flat terrain, slight inclines, and areas with minor obstacles such as rocks and small plants. Navigation achieved a 90% obstacle avoidance success rate. The 10% failure cases were attributable to steep inclines and loose soil, where wheel traction was insufficient to maintain directional stability. Future incorporation of track-based mobility or wider tires is recommended for such conditions.

5.3 Seed Sowing

Seed placement efficiency was 85–90%, dependent on seed type and soil condition. The slider-crank mechanism enabled programmable seed-to-seed spacing. Initial testing without spacing control resulted in continuous seed flow; after code modification with configurable delays, uniform placement was achieved. The robot maintained continuous forward motion during sowing, significantly reducing manual effort.



5.4 Drilling

The drilling unit successfully created holes of the required depth and spacing for seed placement. It performed efficiently in loose and medium-hardness soil conditions. In very dry or compacted soil, the rotational speed of the drill bit decreased slightly; however, overall performance remained satisfactory, and hole depth was within acceptable tolerances for seed germination.



5.5 Ploughing

The ploughing tool penetrated soil to a depth of 4–6 cm, sufficient for basic seedbed preparation. Efficiency was highest in loose or moderately moist soil and decreased in dry, compacted conditions. The ploughing operation successfully loosened top-soil, removed weeds, and prepared furrows in test plots.



5.6 Summary of Performance Metrics

Task	Key Metric	Result
Irrigation	Soil moisture increase / 30 min	~20%
Irrigation	Area covered per tank	~500 m ²
Navigation	Obstacle avoidance rate	90%
Seed Sowing	Placement efficiency	85–90%
Ploughing	Soil penetration depth	4–6 cm
Overall	Water usage reduction	~23%
Overall	Labor productivity gain	3–4×

Table 2. Experimental Performance Summary

6. Conclusion

This paper presented the design, development, and experimental validation of a Solar Powered Multipurpose Agriculture Robot built around the ESP32 microcontroller. The prototype successfully automated four core farming operations — ploughing, seed drilling, seed sowing, and irrigation — within a single solar-powered platform. The dual-mode operation (Automatic and Manual) provides farmers with the flexibility of both fully autonomous and remotely guided operation. Real-time field data (soil moisture, temperature, humidity) is continuously uploaded to the ThingSpeak IoT cloud, enabling data-driven farm management.

Quantitative results demonstrated a 23% reduction in water consumption, an 85–90% seed placement efficiency, 4–6 cm ploughing depth, and a 3–4× improvement in labor productivity relative to manual methods. The 90% obstacle avoidance rate confirms feasibility for real-field deployment, subject to further refinement on rough terrain.

The modular hardware and software architecture is inherently scalable: battery and solar panel upgrades can extend per-charge field coverage to 1–2 acres, while fleet-management integration via a shared ThingSpeak dashboard can enable coordinated multi-robot operation on larger farms. Future enhancements include GPS-RTK autonomous navigation, camera-based AI crop disease detection, variable-rate fertilizer dispensing, and edge AI (TensorFlow Lite on ESP32-S3) for real-time pest

identification. This work demonstrates that affordable, smart agricultural automation is a practical and deployable solution today, with significant potential to transform smallholder farming in India and similar developing economies.

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References

- [1] Shamshiri, R. et al. (2018). Research and development in agricultural robotics: A perspective of digital farming. *International Journal of Agricultural and Biological Engineering*, 11(4), 1–14. <https://doi.org/10.25165/j.ijabe.20181104.4278>
- [2] Duckett, T. et al. (2018). *Agricultural Robotics: The Future of Robotic Agriculture*. UK-RAS White Papers, EPSRC UK Robotics and Autonomous Systems Network.
- [3] Droukas, L. et al. (2022). A Survey of Robotic Harvesting Systems and Enabling Technologies. *Journal of Intelligent & Robotic Systems*, 107(2), 21. <https://doi.org/10.1007/s10846-022-01793>
- [4] Rajendran, S. et al. (2023). Towards Autonomous Selective Harvesting: A Review of Robot Perception, Robot Design, Motion Planning and Control. *Journal of Field Robotics*, 41, 2247–2279. <https://doi.org/10.1002/rob.22230>
- [5] Ahn, H. et al. (2018). An Overview of Perception Methods for Horticultural Robots: From Pollination to Harvest. *arXiv preprint, IROS 2018*. <https://arxiv.org/abs/1807.03124>
- [6] Shamshiri, R. & Hameed, I.A. (2024). *Mobile Robots in Digital Farming*. Springer.
- [7] Vougioukas, S.G. (2019). Agricultural Robotics. *Annual Review of Control, Robotics, and Autonomous Systems*, 2, 365–392. <https://doi.org/10.1146/annurev-control-053018-023617>
- [8] Botta, A. et al. (2022). A Review of Robots, Perception, and Tasks in Precision Agriculture. *Applied Mechanics*, 3(3), 830–854. <https://doi.org/10.3390/applmech3030049>
- [9] Fontani, A. et al. (2025). A Systematic Review of 59 Field Robots for Agricultural Tasks. *Agronomy*, 15(9), 2185. <https://doi.org/10.3390/agronomy1509218>
- [10] Tanwar, V. et al. (2026). Agri-robotics in smallholder agriculture: A comprehensive review. *Plant Science Today*, 13(sp1), 01–09.
- [11] Hymavathi, B. et al. (2020). Design and Structure of Multi-Purpose Agricultural Robot. *International Journal of Engineering Research & Technology (IJERT)*, 9(5).
- [12] Madiwalar, S. et al. (2020). A Survey on Solar Powered Autonomous Multipurpose Agricultural Robot. 2020 2nd International Conference on Innovative Mechanisms for Industry Applications (ICIMIA), 184–189. <https://doi.org/10.1109/ICIMIA48430.2020.90749>
- [13] Chavan, A. et al. (2022). Review on Multipurpose Agricultural Robots. Conference Paper, Google