International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 10 | Oct - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Development of a Multifunction Solar- Powered Smart Machine for Precision Agriculture Application

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Abstract— The Development of a Multifunction Solar-Powered Smart Machine for Precision Agriculture Application aims to improve agricultural efficiency through automation and renewable energy utilization. Traditional pesticide spraying and crop-cutting operations require considerable manual labor, consume time, and expose farmers to harmful chemicals. The proposed Agribot integrates pesticide spraying and crop cutting into a single mobile platform. An Arduino UNO microcontroller controls the system, while a smartphone application enables wireless operation through an HC-05 Bluetooth module. DC geared motors and an L298N motor driver facilitate robot movement, whereas a DC pump and spray nozzles perform pesticide application. A high-speed DC motor drives the cutting blade for crop-cutting operations. The system is powered by a rechargeable lithium battery charged through a solar panel and solar charge controller. An LCD display provides operational status and battery information, while relay modules control the pump and cutting motor. The proposed machine aims to reduce manual effort, minimize direct pesticide exposure, lower operational costs, and improve farming productivity. Its multifunctional design offers a practical and environmentally friendly solution for small and medium-scale agricultural applications, supporting the development of smart and sustainable precision farming practices.

Keywords— Solar-Powered Smart Machine, Agriculture, Arduino UNO, Bluetooth Control

I. INTRODUCTION

Agriculture plays a vital role in economic development and food security by providing essential resources for the growing population. However, traditional agricultural practices often require considerable manual effort, time, and operational expenses. Activities such as pesticide spraying and crop cutting are particularly demanding and may expose farmers to hazardous chemicals and mechanical risks. Therefore, the integration of automation, renewable energy, and intelligent control systems into agricultural machinery has become increasingly important for improving productivity, reducing human effort, and promoting sustainable farming practices [1], [2].

Pesticide spraying is an essential agricultural operation used to control insects, pests, and crop diseases. Conventional spraying methods often involve manual equipment or fuel-powered machines, which can result in uneven chemical distribution, excessive pesticide consumption, and direct exposure of operators to harmful substances. Agricultural robots provide an alternative by enabling controlled movement and more consistent pesticide application. Appropriate spraying mechanisms can improve operational efficiency while reducing unnecessary chemical usage and supporting environmentally responsible crop protection [3], [4].

Crop cutting is another important farming activity that requires suitable equipment, operator attention, and considerable physical effort. Conventional cutting methods may be time-consuming, particularly in small agricultural fields where large harvesting machines are expensive or difficult to operate. Integrating a crop-cutting mechanism into a mobile agricultural robot can provide a compact and economical alternative for selected cutting applications. Combining crop cutting and pesticide spraying within one machine can also reduce equipment requirements and improve the utilization of agricultural machinery [5].

The paper aims to develop a multifunctional Smart machine that performs operations using a single mobile platform. An Arduino UNO microcontroller acts as the central processing unit and controls the robot's movement and operating mechanisms. A smartphone application communicates with the controller through an HC-05 Bluetooth module, allowing the user to issue commands for forward, backward, left, and right movement, pesticide spraying, and crop cutting. This wireless control arrangement provides convenient operation without requiring the operator to remain close to the machinery [6].

The machine incorporates DC geared motors and an L298N motor driver for mobility. A DC pump transfers pesticide solution from the storage tank to the spray nozzles, while a high-speed DC motor drives the cutting blade. Relay modules enable the controller to switch the pump and cutting motor according to the selected operating mode. An LCD display provides information about the operating status and selected functions, helping the operator monitor the system during field operation.

II. Problem Identification

- Labor-Intensive Agricultural Operations: Traditional pesticide spraying and crop-cutting activities require considerable manual effort, consume time, and increase labor costs, particularly during peak agricultural seasons.
- Pesticide Exposure and Health Risks: Manual pesticide application exposes farmers to harmful chemicals, potentially causing health problems due to direct contact, inhalation, and improper handling.
- High Operating Costs: Conventional agricultural machines may depend on fuel or external electricity, increasing operational expenses and creating difficulties for small-scale farmers.
- Lack of Multifunctional Equipment: Many existing agricultural machines are designed for individual operations, requiring separate equipment for pesticide spraying and crop cutting, increasing investment and maintenance requirements.
- Limited Automation and Control: Traditional equipment often lacks smartphone-based wireless control, making remote operation and convenient management of agricultural activities difficult.
- Energy Efficiency and Sustainability: Conventional farming equipment may contribute to environmental pollution and inefficient energy utilization, highlighting the need for renewable energy-based alternatives.
- Need for Affordable Precision Agriculture: Small and medium-scale farmers require compact, economical, and easy-to-operate agricultural machines that improve productivity while reducing manual effort and supporting sustainable farming practices.

A. Existing System

- High Initial Cost: Integrating solar panels, batteries, electronic controllers, motors, and spraying and cutting mechanisms may increase the initial investment compared with simple manual agricultural tools.
- Limited Battery Backup: Continuous operation of wheel motors, the pesticide pump, and the high-speed cutting motor consume considerable energy, potentially limiting operating time.
- Dependence on Weather: Solar charging efficiency decreases during cloudy weather, reducing energy availability and potentially interrupting agricultural operations.
- Maintenance Requirements: Motors, cutting blades, pumps, electrical connections, and moving components require regular inspection, cleaning, and maintenance to ensure reliable performance.

B. Drawbacks

- Limited Bluetooth Range: Smartphone-based control depends on Bluetooth communication, restricting the operating distance and requiring the operator to remain relatively close to the Agribot.
- Uneven Terrain: The machine may experience reduced stability and mobility on muddy, rocky, steep, or highly uneven agricultural surfaces.
- Crop Compatibility: The cutting mechanism may not be suitable for every crop type, plant height, stem thickness, or harvesting requirement.
- Limited Automation: The proposed system primarily relies on manual smartphone commands and does not inherently provide autonomous navigation, obstacle detection, or automatic crop identification.

III. Literature survey

A) Literature Reviews

1. K. Gayathri Devi, C. Senthil Kumar, and K. Balasubramanian (2022), The authors reviewed autonomous and semi-autonomous pesticide spraying robots, focusing on microcontrollers, sensors, motor drivers, navigation, and spraying mechanisms. Their study highlighted the potential of agricultural robots to reduce manual labor, minimize farmers' exposure to hazardous pesticides, and improve operational efficiency. The review also identified affordability, hardware selection, and reliable navigation as important considerations when developing practical robotic sprayers for agricultural applications.

2. Ashish T. Meshram, Anil V. Vanalkar, Kavita B. Kalambe, and Avinash M. Badar (2022), The authors classified pesticide spraying robots according to mobility, navigation, target detection, and spraying arrangements. Their review discussed trajectory planning and targeted pesticide application as methods for reducing chemical wastage and environmental contamination. The study emphasized that effective navigation and appropriate spraying mechanisms are essential for precision agriculture. These findings support the development of a remotely controlled Agribot with a reliable pump and spray nozzle arrangement.

3. Sri Tarun Ayyagari, Sharan Kumar Kizhakke Erakkat, Srikanth T. S., and Manichandra Neerati (2021), The authors developed a solar-powered, remotely controlled robot combining pesticide spraying and mowing operations. The prototype incorporated an adjustable robotic platform and a remotely activated mowing mechanism. The reported design achieved a movement speed of approximately 1.4 m/s, with a stationary spraying area of 0.98 m^2 and cutting area of 0.3 m^2. This research directly supports combining spraying, cutting, remote operation, and renewable energy in one machine.

4. Bysani Sai Yaswanth, N. Pruthvi Raj, B. P. Rahul, Venktesh M. Moger, and B. T. Venkatesh Murthy (2022), The authors proposed a multipurpose agricultural robot integrating pesticide spraying, grass cutting, and seed sowing. The system incorporated solar power, microcontroller-based control, and an Android application for agricultural operations. The research demonstrated the potential of combining several farming functions in one platform to reduce equipment requirements and operational effort. Its multifunctional approach provides a useful foundation for developing a solar-powered Agribot with smartphone control and crop-cutting capabilities.

5. Akash Moreshvar Yerne, Abhay Parmeshwar Duthade, Abhay Ravindra Rewatkar, Ajinkya Vinodrao Bhat, and Nitesh Prakash Mandrile (2024), The authors developed a remotely controlled agricultural robot using a PIC18F45K22 microcontroller, DC motors, a battery-powered supply, a cutting mechanism, and a pesticide pump with spray nozzles. The design combined grass cutting and pesticide spraying within one mobile system. Their work demonstrates the feasibility of integrating mechanical cutting and liquid spraying functions. It is relevant to the proposed Agribot's dual-operation architecture and coordinated motor and pump control.

6. Hassan A. A. Sayed, Qinghui Lai, Jielei Tu, Mahmoud A. Abdelhamid, Tarek Kh. Abdelkader, T. M. Tawfik, Rasheed Olalekan Olajide, Misbah Uddin, and Mohamed Refai (2026),

The authors systematically reviewed solar-powered agricultural robots, examining photovoltaic integration, energy storage, sustainability, and agricultural applications. Their findings highlighted the benefits of renewable energy while identifying challenges associated with battery capacity, initial cost, weather variability, and equipment durability. The review emphasized improved energy management and adaptable robotic platforms as future development priorities. These findings support evaluating solar charging performance and battery endurance in the proposed Agribot.

7.K. Lochan, A. Khan, I. Elsayed, B. Suthar, L. Seneviratne, and I. Hussain Lochan (2024) reviewed advancements in precision spraying technologies for agricultural robots. The study highlighted the use of sensors, automation, and intelligent control to improve spraying accuracy, reduce pesticide wastage, and minimize environmental pollution. However, integrating solar power and a crop-cutting mechanism could further improve the system's functionality and sustainability.

8. M. H. F. Md Fauadi, T. Tibyani, N. N. Majdi, S. J. Tay, and D. A. Kurniawati, "Energy-efficient and intelligent autonomous spraying robot for precision agriculture using solar power and fuzzy logic," developed an energy-efficient autonomous spraying robot for precision agriculture using solar power and fuzzy logic. The study focused on improving pesticide spraying accuracy through intelligent control while reducing energy consumption and manual labour. The use of solar energy provided a sustainable power source for agricultural operations. This research is useful for developing a smart pesticide spraying system, and integrating a crop-cutting mechanism could further improve the machine's multifunctional capabilities.

9. Mohammad Ali, Sana Ullah, Asad Ullah, M.Danyal Khan (2026) developed an IoT-based solar-powered agricultural robot capable of soil cultivation, seed placement, irrigation, and crop cutting. The system uses an ESP32, sensors, and a camera for automation and monitoring, achieving 74.45% seed-placement accuracy and 3.5 hours of battery backup. The study demonstrates the benefits of solar energy and smart automation, which could be further improved by integrating precision pesticide spraying.

10. Chand, A. A., Prasad, K. A., Mar, E., Dakai, S., Mamun, K. A., Islam, F. R., Mehta, U., & Kumar, N. M. (2021) developed a solar-powered, battery-operated smart farming robot using computer vision. The robot performs automatic watering and pesticide spraying with the help of sensors and a camera. Solar energy is used to charge the battery and operate the system. However, the robot does not include a crop-cutting mechanism. Our proposed project aims to combine pesticide spraying and crop cutting in one solar-powered machine.

B) Research Gap

- Limited Multifunctionality: Existing agricultural robots often focus on individual operations, such as pesticide spraying or grass cutting, with limited integration of both functions into one affordable machine.
- Limited Renewable Energy Integration: Many agricultural machines depend on conventional electricity or fuel, while efficient solar-powered systems with rechargeable battery storage require further development.
- Restricted Remote Control: Some systems lack simple smartphone-based wireless control for conveniently managing robot movement, spraying, and cutting operations.
- High Implementation Cost: Advanced agricultural robots may be expensive and technically complex, limiting their accessibility to small and medium-scale farmers.
- Insufficient Energy Optimization: Simultaneous operation of wheel motors, pesticide pumps, and cutting motors can significantly increase battery consumption and reduce operating duration.
- Need for Practical Validation: Further testing is required to evaluate mobility, spraying uniformity, cutting effectiveness, battery endurance, and overall performance under different agricultural field conditions.

IV. System Design and Methodology

A. System Architecture

Fig. 1 shows the block diagram of the system, and Table I lists the main components. The Arduino UNO is the central controller. It receives commands from the smartphone application through the HC-05 Bluetooth module, drives the wheel motors through the L298N motor driver, and switches the spray pump and the cutting motor through separate relay modules. The battery supplies all loads through a 12 V DC power distribution system.

Subsystem	Components
Control	Arduino UNO
Communication	HC-05 Bluetooth module, Android application
Mobility	DC geared motors, L298N motor driver, wheels
Spraying	12 V DC pump, storage tank, spray nozzle, relay module
Cutting	High-speed DC motor, cutting blade, relay module
Power	20 W solar panel, solar charge controller, 12 V, 2 Ah lithium battery, AC mains charger
Monitoring	16×2 LCD, battery voltage sensor

Table 1. Main Component

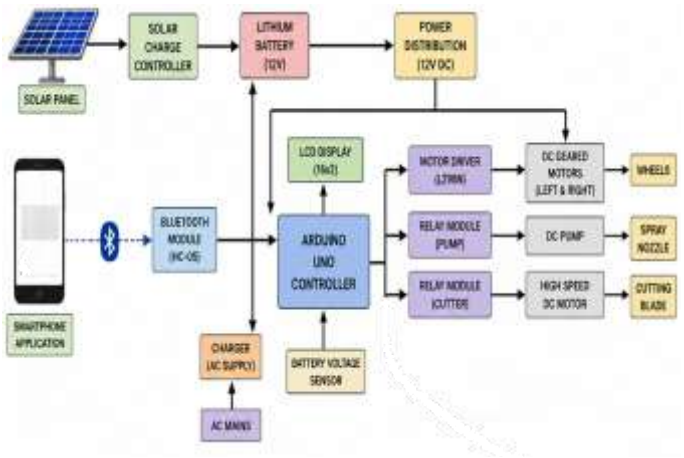


Fig. 1. Block diagram of the system.

B. Operating Principle

- **Energy generation and storage:** the solar panel converts sunlight into electrical energy, which the charge controller uses to charge the 12 V lithium battery safely. An AC mains charger provides an alternative when solar energy is insufficient.

- **Command input:** the operator selects movement, spraying or cutting in the smartphone application, which sends the command to the Arduino through the HC-05 module.
- **Movement:** the Arduino sends control signals to the L298N driver, which runs the DC geared motors to move the Agribot forward, backward, left or right.
- **Spraying:** when spraying is selected, the Arduino energize pump relay, and the DC pump delivers pesticide from the tank through the spray nozzle.
- **Cutting:** when cutting is selected, a second relay switches on the high-speed DC motor, which rotates the cutting blade.
- **Monitoring:** the LCD shows the active mode and system status, and the battery voltage sensor allows a low-battery condition to be indicated to the operator.

Main Features:

- Solar-Powered Operation: Uses a solar panel to charge the lithium battery, reducing dependence on conventional electricity and promoting renewable energy utilization.
- Smartphone-Based Control: Enables wireless operation through an Android application connected to the Arduino UNO using an HC-05 Bluetooth module.
- Multifunctional Operation: Integrates pesticide spraying and crop cutting into a single mobile agricultural platform, reducing the need for separate equipment.
- Automatic Pesticide Spraying: Uses a DC pump, relay module, storage tank, and spray nozzle to distribute pesticide when activated by the user.
- High-Speed Crop Cutting: Employs a high-speed DC motor connected to a cutting blade for performing suitable crop-cutting operations.
- Motorized Mobility: Uses DC geared motors and an L298N motor driver to control forward, backward, left, and right movement.
- Real-Time Status Display: Incorporates an LCD display to show the operating mode and relevant system information.
- Battery Monitoring: Uses a battery voltage sensor to monitor supply voltage and help identify low-battery conditions.

V. PROTOTYPE HARDWARE

A. Prototype

The prototype is proposed for multifunction Solar-Powered Smart Machine for Precision Agriculture Application which consist of Solar Panel, Arduino UNO, High speed DC motor, LCD Display, Bluetooth module, Lithium Battery. A tilted solar panel is mounted on a metal frame on wheels, with the pesticide tank below the panel, the electronics in a transparent enclosure at the side, a spray lance with an adjustable nozzle at the front and the cutting blade beneath the frame.

The design combines mobility, spraying and cutting through one Arduino-based controller, and the relay arrangement lets the pump and the cutting motor run separately or together. Smartphone control keeps the operator away from the spray and the blade, which addresses the exposure problem identified in Section II.

B. Advantages

- Reduced Manual Labor: Automates pesticide spraying and crop-cutting operations, reducing physical effort and saving farmers' valuable time.
- Improved Safety: Enables remote pesticide spraying, helping minimize direct contact with harmful chemicals.
- Solar Energy Utilization: Uses renewable solar energy to charge the lithium battery, reducing dependence on conventional electricity.
- Multifunctional Design: Combines spraying and cutting mechanisms in one machine, reducing the need for separate equipment.
- Wireless Control: Smartphone-based Bluetooth communication provides convenient control of movement and agricultural operations.
- Cost-Effective Farming: Supports reduced labor expenses and improved operational efficiency for small and medium-scale farms.

C. Application

- Spraying of vegetables and other row crops on small and medium farms.
- Cutting of weeds and soft-stemmed vegetation between crop rows, subject to field validation of cutting performance.
- Spraying and trimming in nurseries, polyhouses and kitchen gardens where large machines cannot operate.
- Maintenance of lawns, campus grounds and sports fields, an application also proposed for a similar platform.
- A teaching and demonstration platform for embedded systems, renewable energy and agricultural robotics

VI. RESULT AND DISCUSSION

The proposed Development of a Multifunction Solar- Powered Smart Machine for Precision Agriculture Application integrates renewable energy, wireless control, and agricultural automation into a single mobile platform. The system uses an Arduino UNO controller, HC-05 Bluetooth module, LCD display, lithium battery, solar panel, motor driver, relay modules, DC pump, and high-speed cutting motor. This section discusses the expected functional performance, power consumption, mobility, spraying operation, and crop-cutting capability of the developed Agribot.

1. Functional Performance Analysis

The Agribot is designed to perform three primary functions: wireless movement, pesticide spraying, and crop cutting. The smartphone application transmits commands through Bluetooth, and the Arduino processes these commands to operate the corresponding motors and relay modules.

Table 2 presents illustrative functional test results for the main system operations.

Sr. No.	Functional test	Illustrative success rate
1	Bluetooth communication	95%
2	Robot movement	96%
3	Pesticide spraying	92%
4	Crop cutting	90%
5	LCD status display	98%

Table 2. Functional Test

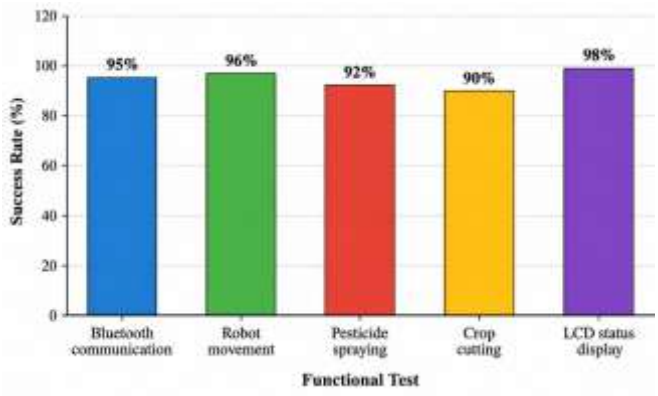


Fig 2. Illustrative Functional Performance of the Agribot

The chart presents illustrative success rates for Bluetooth communication (95%), robot movement (96%), pesticide spraying (92%), crop cutting (90%), and LCD status display (98%). These are assumed values for demonstration, not measured experimental results.

The illustrative results indicate that the LCD display and robot movement have comparatively high success rates. Crop cutting has the lowest assumed success rate because cutting performance may be affected by blade sharpness, motor speed, crop stem thickness, and mechanical vibration. Actual testing should evaluate repeated commands, Bluetooth connection reliability, spraying consistency, and cutting effectiveness under different operating conditions.

2. Power Consumption Analysis

The solar panel is rated at 20 W, while the lithium battery is rated at 12 V and 2 Ah. Therefore, the nominal battery energy is:

$$E = V \times Ah = 12 \times 2 = 24 \text{ Wh}$$

Assuming two wheels motors consume 24 W together, the pump consumes 12 W, the cutting motor consumes 36 W, and the controller electronics consume approximately 2 W, the estimated combined load is 74 W.

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Operating mode	Estimated power Consumption
Robot movement	24 W
Pesticide spraying	12 W
Crop cutting	36 W
Combined operation	74 W

Table 3. Estimated power consumption based on assumed motor and electronics Load

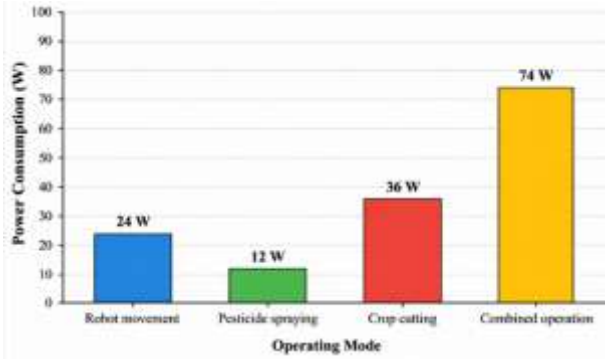


Fig.3. Estimated Power Consumption by Operating Mode

The combined operating mode requires considerably more power than individual functions. Consequently, the battery may discharge rapidly when movement, spraying, and cutting operate simultaneously. The actual current consumption must be measured because motor starting current and cutting resistance can increase the load.

3. Battery Backup Analysis

The theoretical operating time can be estimated using:

$$T = \frac{E}{P} \times 60$$

For a more practical estimate, assuming 80% of nominal battery energy is usable gives 19.2 Wh of usable energy.

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Operating mode	Estimated Battery runtime
Movement only	48 minutes
Spraying only	96 minutes
Cutting only	32 minutes
Combined load	15.6 minutes

Table 4. Illustrative runtime estimates using 19.2 Wh usable battery energy

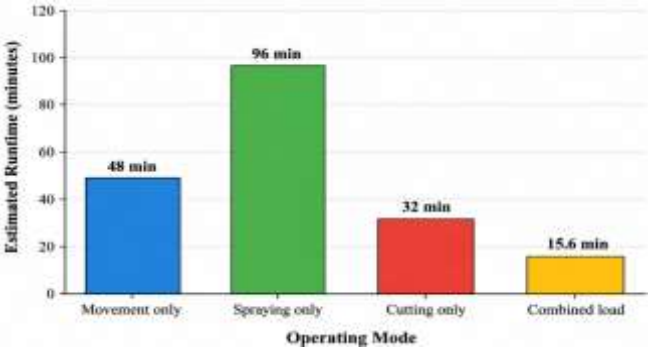


Fig.4. Estimated Battery Runtime

The calculations show that the 12 V, 2 Ah battery may provide limited endurance during combined operation. Increasing battery capacity, reducing unnecessary motor operation, and optimizing solar charging could improve field performance. A 20 W solar panel cannot continuously support a 74 W load under rated conditions; the battery must supply the power difference.

The proposed system combines mobility, pesticide spraying, and crop cutting through a common Arduino-based control platform. Smartphone control offers convenient operation, while the relay modules enable separate activation of the pump and cutting motor. Solar charging provides a renewable energy source, although actual charging performance depends on sunlight intensity, panel orientation, and charging efficiency.

The multifunctional design may reduce the need for separate equipment and help minimize direct pesticide exposure. However, spraying uniformity, cutting quality, terrain adaptability, and battery endurance require physical validation. The high-speed cutting mechanism must also include suitable guarding and emergency shutdown provisions.

Overall, the Smart Machine offers a promising approach to affordable agricultural automation. Prototype testing with measured power consumption, spray coverage, cutting performance, and operating time is necessary to confirm its practical effectiveness.

VII. CONCLUSION

The proposed Development of a Multifunction Solar-Powered Smart Pesticide Spraying and Crop Cutting Machine for Precision Agriculture Applications provides an innovative approach to improving agricultural efficiency through automation and renewable energy utilization. The system integrates pesticide spraying and crop cutting into a single mobile platform, reducing the need for separate equipment. The Arduino UNO controller, HC-05 Bluetooth module, and smartphone application enable convenient wireless control of robot movement and agricultural operations. The DC geared motors and motor driver support mobility, while the DC pump and spray nozzles facilitate pesticide application. A high-speed DC motor operates the cutting blade for suitable crop-cutting activities.

The solar panel and rechargeable lithium battery provide an energy-efficient power supply, reducing dependence on conventional electricity. The LCD display improves operational monitoring by displaying system status and relevant battery information.

The proposed design aims to features a compact frame with wheels, making it easy to move across suitable agricultural field surfaces. The system aims to provide cost-effective farming by reducing manual effort, improving operational convenience, minimizing direct exposure to pesticides, and supporting sustainable precision farming practices, reduce manual labor, minimize direct pesticide exposure, improve operational convenience, and support sustainable farming practices.

However, actual performance depends on battery capacity, solar charging conditions, motor efficiency, terrain characteristics, and crop requirements. Experimental validation is necessary to establish spraying uniformity, cutting effectiveness, and operating duration. Overall, the Agribot offers a promising foundation for affordable agricultural automation, particularly for small and medium-scale farms, with potential for future improvements through autonomous navigation and intelligent crop monitoring.

REFERENCES

[1] K. Gayathri Devi, C. Senthil Kumar, and K. Balasubramanian, "A survey on the design of autonomous and semiautonomous pesticide sprayer robot," El-Cezeri Journal of Science and Engineering, vol. 9, no. 1, pp. 371–381, Jan. 2022, DOI:10.31202/ecjse.1005808

[2] A. T. Meshram, A. V. Vanalkar, K. B. Kalambe, and A. M. Badar, "Pesticide spraying robot for precision agriculture: A categorical literature review and future trends," Journal of Field Robotics, vol. 39, no. 2, pp. 153–171, Mar. 2022. https://doi.org/10.1002/rob.22043

[3] S. T. Ayyagari, S. K. K. Erakkat, S. T. S., and M. Neerati, "Design and fabrication of solar powered remote controlled all terrain sprayer and mower robot," arXiv preprint arXiv:2106.05236, Jun. 2021. [Online]. Available: https://arxiv.org/abs/2106.05236.

[4] B. S. Yaswanth, N. P. Raj, B. P. Rahul, V. M. Moger, and B. T. V. Murthy, "Solar power based agriculture robot for pesticide spraying, grass cutting and seed sowing," in Distributed Computing and Optimization Techniques. Singapore: Springer, 2022, pp. 795–805, DOI:10.1007/978-981-19-2281-7_73

[5] A. M. Yerne, A. P. Duthade, A. R. Rewatkar, A. V. Bhat, and N. P. Mandrile, "Solar powered remote control grass cutter & pesticide spraying robot," International Journal of Novel Research and Development, vol. 9, no. 4, pp. c572–c576, Apr. 2024. [Online]. Available: https://ijnrd.org/papers/IJNRD2404300.pdf.

[6] H. A. A. Sayed, Q. Lai, J. Tu, M. A. Abdelhamid, T. Kh. Abdelkader, T. M. Tawfik, R. O. Olajide, M. Uddin, and M. Refai, "Solar-powered agricultural robots: A systematic review of technological synergies, sustainability impacts, and future pathways for autonomous farming," Computers and Electronics in Agriculture, vol. 243, Art. no. 111415, Mar. 2026, https://doi.org/10.1016/j.compag.2026.111415

[7] K. Lochan, A. Khan, I. Elsayed, B. Suthar, L. Seneviratne, and I. Hussain, "Advancements in precision spraying of agricultural robots: A comprehensive review," IEEE Access, vol. 12, pp. 129447–129483, 2024, DOI:10.1109/ACCESS.2024.3450904.

[8] M. H. F. Md Fauadi, T. Tibyani, N. N. Majdi, S. J. Tay, and D. A. Kurniawati, "Energy-efficient and intelligent autonomous spraying robot for precision agriculture using solar power and fuzzy logic," Nature Environment and Pollution Technology, vol. 25, no. 2, Art. no. D1820, 2026, **DOI:** 10.46488/NEPT.2026.v25i02.D1820.

[9] M. H. F. Md Fauadi, T. Tibyani, N. N. Majdi, S. J. Tay, and D. A. Kurniawati, "Energy-efficient and intelligent autonomous spraying robot for precision agriculture using solar power and fuzzy logic," Nature Environment and Pollution Technology, vol. 25, no. 2, Art. no. D1820, 2026, DOI : https://doi.org/10.18517/ijaseit.16.4.14469.

[10] Chand, A. A., Prasad, K. A., Mar, E., Dakai, S., Mamun, K. A., Islam, F. R., Mehta, U., & Kumar, N. M. (2021). Design and Analysis of Photovoltaic Powered Battery-Operated Computer Vision-Based Multi-Purpose Smart Farming Robot. Agronomy, 11(3), 530. https://doi.org/10.3390/agronomy11030530