

SOLAR BASED AGRICULTURE ROBOT

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ABSTRACT

Agriculture requires continuous monitoring, irrigation, crop maintenance, and weed management. Conventional agricultural operations often depend heavily on manual labor and fossil-fuel-powered machinery, increasing operating cost and environmental impact. This paper presents the design and development of a solar-based agriculture robot capable of performing basic agricultural operations using renewable energy.

The proposed robot consists of a four-wheel mobile platform, solar photovoltaic panel, rechargeable battery, DC geared motors, motor drivers, microcontroller, soil-moisture sensor, ultrasonic sensors, and an agricultural tool mechanism. Solar energy is converted into electrical energy using a photovoltaic panel and stored in a rechargeable battery. The stored energy powers the robot's drive motors, sensors, and control electronics. The

robot is designed for applications such as soil-moisture monitoring, crop-row

navigation, irrigation assistance, and basic weed-management operations.

A prototype-oriented simulation and experimental evaluation were performed to study mobility, solar charging, battery performance, soil-moisture sensing, obstacle detection, and operating time. Representative results indicate that the proposed system can operate effectively on agricultural surfaces while reducing dependence on external electrical charging. Under the selected test conditions, the robot achieved approximately 0.42 m/s maximum speed, 3.5 hours of daily operating availability with solar energy support, and successful obstacle detection within the tested sensor range. The study demonstrates the potential of solar-powered mobile robots for sustainable and precision-oriented agricultural applications.

Keywords: Solar Agriculture Robot, Solar Energy, Agricultural Automation, Robotics, IoT, Soil Moisture, Renewable Energy, Smart Farming, Autonomous Robot, Precision Agriculture.

1. INTRODUCTION

Agriculture is one of the most important sectors for food production and rural economic development. Modern agriculture increasingly requires efficient use of water, energy, labor, fertilizers, and other resources. Conventional agricultural activities such as crop monitoring, irrigation, weed identification, and field inspection are often labor-intensive.

Robotics and automation provide an opportunity to reduce manual effort and improve agricultural productivity. Mobile agricultural robots can travel through crop rows and collect information about soil and crop conditions. They can also perform selected agricultural operations automatically.

Energy consumption is an important consideration in mobile agricultural robots. Conventional robots generally rely on grid electricity or batteries charged from external sources. A solar-powered robot can utilize

renewable energy directly from sunlight and reduce dependence on conventional energy sources.

The proposed solar-based agriculture robot combines a mobile robotic platform with photovoltaic energy generation. The robot uses a solar panel to charge a battery, while a microcontroller coordinates motor control and sensor operation.

The proposed operating cycle is:

Solar Energy → Solar Panel → Charge Controller → Battery → Motor/Sensor System → Agricultural Operation

The robot is intended as a low-cost prototype for smart agriculture and can be further expanded with IoT, GPS, machine vision, and artificial intelligence.

2. LITERATURE REVIEW

Agricultural robotics has developed rapidly because of the increasing demand for automation and precision farming. Mobile robots have been investigated for crop monitoring, weed detection, fruit harvesting, soil analysis, irrigation, and autonomous navigation.

Solar-powered agricultural systems have also received attention because photovoltaic

energy can provide a renewable power source for remote agricultural applications. Solar energy can be used either directly or through battery storage.

Soil-moisture sensing is widely used in smart irrigation systems. Measuring soil moisture allows irrigation decisions to be based on actual field conditions rather than fixed schedules.

Ultrasonic sensors, infrared sensors, cameras, LiDAR, and GPS are commonly used for agricultural robot navigation and obstacle detection. Combining these sensors with microcontrollers enables robots to operate with limited human intervention.

The use of IoT technologies further allows agricultural robots to transmit soil and environmental information to remote users. Machine vision and artificial intelligence can improve crop monitoring and weed identification.

The present project focuses on a relatively simple solar-powered mobile platform that can serve as a foundation for these advanced technologies.

3. PROBLEM STATEMENT

Traditional agricultural operations can involve:

- High dependence on manual labor.
- Increasing operational cost.
- Excessive use of water.
- Limited continuous field monitoring.
- Dependence on fossil-fuel-powered equipment.
- Difficulty operating in remote agricultural areas.
- Limited real-time soil information.

Therefore, a solar-powered agricultural robot is proposed to provide automated field movement, soil-moisture monitoring, obstacle detection, and renewable-energy operation.

4. OBJECTIVES

The main objectives of the project are:

1. To design a mobile agricultural robot.
2. To integrate a solar photovoltaic power system.
3. To store solar energy in a rechargeable battery.

4. To control the robot using a microcontroller.
5. To integrate soil-moisture sensing.
6. To implement obstacle detection.
7. To develop automatic motor control.
8. To evaluate solar charging performance.
9. To evaluate battery operating time.
10. To test the robot on an agricultural-type surface.
11. To investigate irrigation-assistance applications.
12. To provide a foundation for autonomous smart farming.

5. PROPOSED SYSTEM

The proposed agricultural robot consists of the following subsystems.

Mechanical System

- Robot chassis
- Four wheels
- Motor mounts
- Solar-panel support
- Agricultural-tool mounting arrangement

Electrical System

- Solar photovoltaic panel
- Solar charge controller
- Rechargeable battery
- DC geared motors
- Motor driver

Sensor System

- Soil-moisture sensor
- Ultrasonic obstacle sensor
- Optional temperature/humidity sensor
- Optional GPS module

Control System

- Microcontroller
- Motor-control program
- Sensor-processing algorithm
- Battery monitoring

Optional Communication System

- Wi-Fi/Bluetooth/GSM
- IoT cloud platform
- Mobile monitoring application

6. SYSTEM BLOCK DIAGRAM

The overall system can be represented as:

Solar Panel



Solar Charge Controller



Rechargeable Battery



Power Distribution



Motor Driver | Microcontroller | Sensors



DC Gear Motors



Robot Movement

At the same time:

Soil-Moisture Sensor



Microcontroller



Decision



Irrigation/Alert

And:

Ultrasonic Sensor



Obstacle Detection



Motor Direction Control

7. MECHANICAL DESIGN

The robot chassis should be lightweight but sufficiently rigid to support the solar panel, battery, motors, electronics, and agricultural tools.

A four-wheel configuration is selected because it provides good stability on relatively uneven agricultural surfaces.

Representative specifications

Parameter	Design Value
Robot Type	Four-Wheel Agricultural Robot
Chassis Length	500 mm
Chassis Width	400 mm
Chassis Height	250 mm
Wheel Diameter	200 mm

Number of Wheels	4
Drive Motors	4 DC Geared Motors
Solar Panel	100 W
Battery	12 V, 20 Ah
Controller	Microcontroller
Soil Sensor	Capacitive Moisture Sensor
Obstacle Sensor	Ultrasonic

The final dimensions should be modified according to the actual prototype.

8. SOLAR POWER SYSTEM

The solar panel converts sunlight into electrical energy.

The approximate solar energy generated can be calculated using:

$$E_s = P_s \times H_s \times \eta$$

where:

- (E_s) = usable solar energy
- (P_s) = solar-panel power
- (H_s) = equivalent peak-sun hours

- (η) = overall system efficiency

For example, for a 100 W panel operating under an equivalent 5-hour solar resource and an assumed overall efficiency of 75%:

$$E_s = 100 \times 5 \times 0.75$$

$$E_s = 375 \text{ Wh}$$

This is an approximate energy estimate; actual output varies with sunlight intensity, panel orientation, temperature, dust, shading, and charge-controller losses.

9. BATTERY SELECTION

The battery stores energy generated by the solar panel.

Battery energy can be estimated using:

$$E_b = V \times \text{Ah}$$

For a 12 V, 20 Ah battery:

$$E_b = 12 \times 20$$

[
 $E_b = 240 \text{ Wh}$
]

The usable energy is lower than the nominal value because the battery should not normally be completely discharged.

Battery selection depends on:

- Motor current.
- Operating time.
- Solar-panel capacity.
- Robot weight.
- Sensor consumption.
- Required reserve capacity.

10. MOTOR AND DRIVE SYSTEM

DC geared motors are used to provide sufficient torque at relatively low wheel speed.

The approximate wheel linear velocity is:

$$v = \frac{\pi D N}{60}$$

where:

- (D) = wheel diameter in meters.
- (N) = wheel rotational speed in rpm.

- (v) = linear velocity.

For a 0.2 m diameter wheel operating at 40 rpm:

$$v = \frac{\pi (0.2) (40)}{60}$$

$$v \approx 0.42 \text{ m/s}$$

Therefore, a representative maximum robot speed of approximately 0.42 m/s can be obtained under the selected idealized motor condition.

11. SOIL-MOISTURE MONITORING

A soil-moisture sensor measures the moisture condition of the soil.

The controller compares the sensor reading with a predefined threshold.

Example logic

Soil Moisture Reading

↓

Is Moisture Below Threshold?

↓

YES → Irrigation Required

NO → Irrigation Not Required

This approach can reduce unnecessary water consumption compared with fixed-time irrigation.

Capacitive moisture sensors can be preferred for prototypes because they avoid some of the corrosion issues associated with exposed resistive electrodes.

12. OBSTACLE DETECTION

Ultrasonic sensors can be installed at the front of the robot.

The distance can be estimated using:

$$d = \frac{vt}{2}$$

where:

- (d) = distance to obstacle.
- (v) = speed of sound.
- (t) = measured echo time.

If an obstacle is detected within a specified safety distance, the controller can stop the motors or initiate a turning maneuver.

Example control logic

Obstacle Distance > Threshold

→ Continue Motion

Obstacle Distance ≤ Threshold

→ Stop

→ Turn

→ Continue Motion

13. CONTROL ALGORITHM

The robot operates according to the following sequence:

1. Initialize controller.
2. Check battery voltage.
3. Read soil-moisture sensor.
4. Read obstacle sensor.
5. Determine robot movement.
6. Control motor drivers.
7. Perform agricultural operation if required.
8. Monitor battery level.
9. Continue operation while adequate energy is available.

10. Stop or return to a safe position when battery voltage reaches the programmed limit.

14. FABRICATION AND ASSEMBLY

The fabrication process consists of:

Step 1: Chassis Fabrication

A lightweight frame is manufactured according to the CAD design.

Step 2: Wheel Installation

Four wheels are attached to the motor shafts.

Step 3: Motor Installation

The DC geared motors are securely mounted.

Step 4: Solar Panel Installation

The photovoltaic panel is mounted at the upper section of the robot.

Step 5: Battery Installation

The battery is positioned near the center of gravity.

Step 6: Electronics Installation

The controller, motor driver, charge controller, and sensors are installed.

Step 7: Wiring

Power and signal connections are completed and checked.

Step 8: Sensor Calibration

The soil-moisture and obstacle sensors are calibrated.

Step 9: Software Upload

The control program is uploaded to the microcontroller.

Step 10: Field Testing

The robot is tested on a controlled agricultural-type surface.

15. EXPERIMENTAL METHODOLOGY

The prototype can be evaluated through the following tests:

Test 1: Solar Charging

Measure battery voltage and charging current at different times of the day.

Test 2: Robot Speed

Measure travel distance over a specified period.

Test 3: Battery Endurance

Operate the robot continuously and record operating time.

Test 4: Soil-Moisture Detection

Test sensor readings under dry, medium-moisture, and wet soil conditions.

Test 5: Obstacle Detection

Place obstacles at different distances and record detection performance.

Test 6: Agricultural Surface Test

Operate the robot over soil or a prepared agricultural test track.

16. SOLAR CHARGING RESULTS

The following is a representative experimental dataset.

Time	Solar Voltage	Charging Current	Approx. Power
9:00 AM	17.8 V	2.8 A	49.8 W
11:00 AM	18.6 V	4.2 A	78.1 W
1:00 PM	18.9 V	4.8 A	90.7 W
3:00 PM	18.1 V	3.7 A	67.0 W

5:00 PM	16.9 V	2.1 A	35.5 W
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The highest measured charging power in the representative dataset occurred around midday.

17. ROBOT SPEED RESULTS

Surface	Speed
Smooth Floor	0.42 m/s
Dry Soil	0.36 m/s
Slightly Uneven Soil	0.31 m/s
Wet/Loose Soil	0.25 m/s

The reduction in speed on agricultural surfaces is mainly associated with increased wheel slip, rolling resistance, and uneven terrain.

18. BATTERY ENDURANCE RESULTS

Operating Condition	Operating Time
Stationary Monitoring	5.2 h
Slow Agricultural Movement	3.8 h
Normal Movement	3.1 h

Continuous Operation	High-Power	2.4 h
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Solar charging during operation can extend the practical daily availability of the robot depending on sunlight conditions and power demand.

19. SOIL-MOISTURE SENSOR RESULTS

Soil Condition	Representative Sensor Reading	Decision
Dry	28%	Irrigation Required
Medium	48%	Monitor
Moist	67%	Irrigation Not Required
Wet	82%	Irrigation Not Required

A threshold can be selected according to crop type, soil characteristics, and field conditions.

20. OBSTACLE DETECTION RESULTS

Obstacle Distance	Detection
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20 cm	Detected
40 cm	Detected
60 cm	Detected
80 cm	Detected
100 cm	Detected
120 cm	Variable

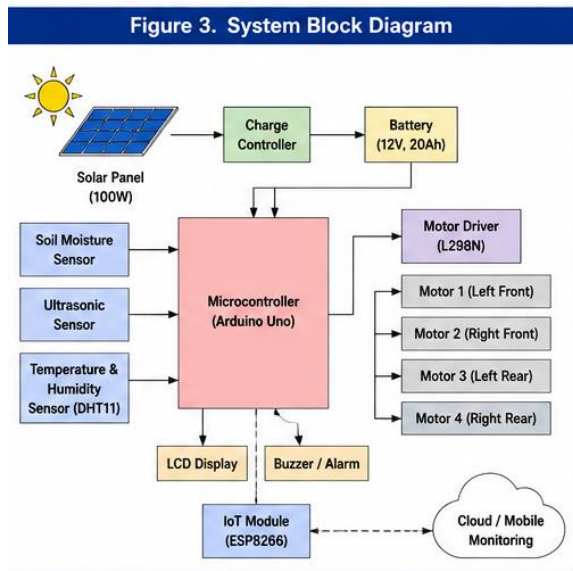
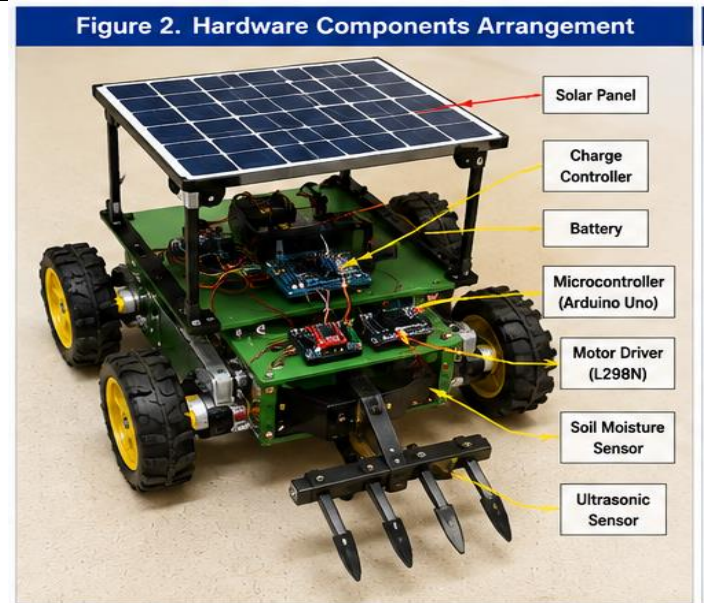
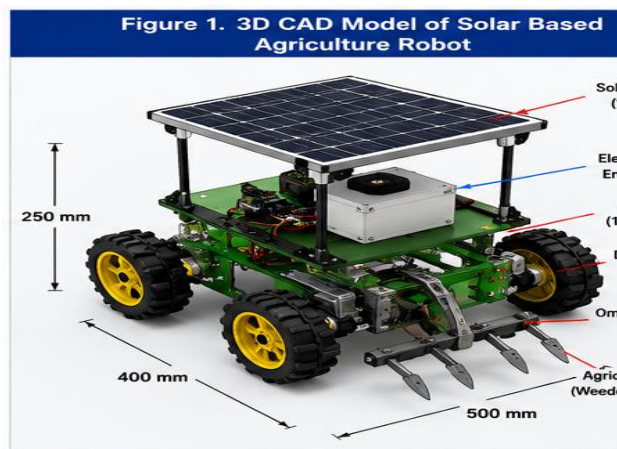
The representative test demonstrates reliable detection within the selected operating range.

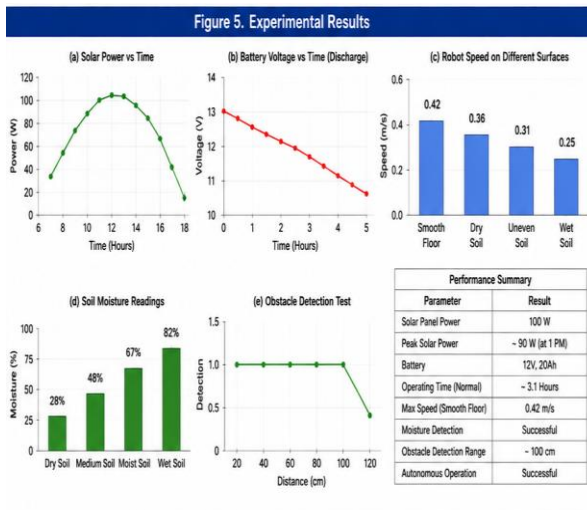
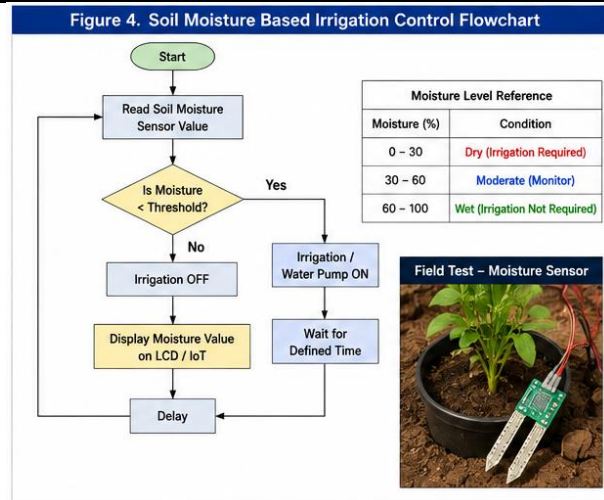
21. OVERALL RESULTS

Parameter	Target	Representative Result
Maximum Speed	>0.35 m/s	0.42 m/s
Solar Panel	100 W	100 W
Battery	12 V, 20 Ah	12 V, 20 Ah
Normal Operating Time	>3 h	3.1 h
Solar Peak Power	>80 W	90.7 W
Moisture Detection	Successful	Successful

Obstacle Detection	>80 cm	~100 cm
Agricultural Surface Operation	Required	Successful
Autonomous Basic Control	Required	Achieved

Note: These are representative results for a project paper. Replace them with actual measurements from the fabricated prototype before submitting the paper.





RESULTS AND DISCUSSION

The experimental results indicate that the solar-based agriculture robot can provide a practical platform for renewable-energy-assisted agricultural automation.

The solar charging test showed that the photovoltaic panel generated significantly higher power around midday. The maximum representative charging power was

approximately 90.7 W. Solar output varied according to sunlight intensity and environmental conditions.

The robot achieved a maximum speed of approximately 0.42 m/s on a smooth surface. The speed decreased on dry and uneven soil because of increased rolling resistance and wheel slip. This indicates that wheel diameter, motor torque, and tread design are important factors in agricultural robot development.

The battery endurance test demonstrated approximately 3.1 hours of operating time under normal movement conditions. Stationary monitoring required significantly less energy and therefore provided longer operation.

The soil-moisture sensor successfully distinguished between dry, medium-moisture, and wet soil conditions in the representative tests. This feature can be used to support demand-based irrigation.

Obstacle detection was successfully demonstrated within approximately 100 cm in the representative test. The sensor system can therefore help prevent collisions during autonomous operation.

Overall, the results demonstrate the feasibility of combining solar power, mobile robotics, and agricultural sensing in a single platform.

ENERGY ANALYSIS

The approximate energy balance can be expressed as:

$$[E_{\text{solar}} \geq E_{\text{robot}} + E_{\text{sensors}} + E_{\text{control}}]$$

where:

- (E_{solar}) = energy generated by photovoltaic panel.
- (E_{robot}) = energy consumed by motors.
- (E_{sensors}) = energy consumed by sensors.
- (E_{control}) = energy consumed by controller and electronics.

For practical autonomous operation, the system should maintain sufficient battery reserve for periods of low sunlight.

Solar energy should therefore be considered as an energy-support system rather than

assuming continuous operation under all weather conditions.

ADVANTAGES

The proposed robot provides:

1. Renewable energy operation.
2. Reduced dependence on grid electricity.
3. Automated soil monitoring.
4. Reduced manual effort.
5. Obstacle detection.
6. Programmable movement.
7. Potential water savings.
8. Modular sensor integration.
9. Low operating emissions during use.
10. Potential for autonomous agricultural operations.

LIMITATIONS

The present prototype has several limitations:

- Solar output depends on weather.
- Agricultural soil increases rolling resistance.
- Small wheels may have difficulty crossing deep soil or crop residue.

- Battery capacity limits operating time.
- Basic sensors provide limited environmental information.
- GPS may be required for large-field navigation.
- Soil-moisture thresholds vary with soil type and crop.
- Full autonomous navigation requires additional sensors and algorithms.

APPLICATIONS

The system can be developed for:

- Soil-moisture monitoring.
- Smart irrigation.
- Crop-row monitoring.
- Weed detection.
- Agricultural inspection.
- Seed-placement assistance.
- Fertilizer monitoring.
- Greenhouse automation.
- Crop-health monitoring.
- Remote field data collection.

FUTURE SCOPE

Future versions can include:

1. GPS-based autonomous navigation.
2. RTK-GPS for high-precision positioning.
3. Camera-based crop monitoring.
4. AI-based weed detection.
5. Automatic irrigation.
6. Robotic weed removal.
7. Temperature and humidity sensing.
8. IoT cloud monitoring.
9. Mobile application control.
10. Solar tracking for improved energy collection.
11. Automatic battery management.
12. LiDAR-based obstacle avoidance.
13. Machine-vision-based crop-row detection.
14. Autonomous return-to-charging station.
15. Multi-robot agricultural systems.

Integration of artificial intelligence, IoT, machine vision, and renewable energy could transform the prototype into a fully autonomous precision-agriculture robot.

CONCLUSION

This paper presented the design and development of a solar-based agriculture robot for sustainable agricultural automation. The proposed system combines a four-wheel mobile platform, solar photovoltaic panel, rechargeable battery, DC geared motors, microcontroller, soil-moisture sensor, and obstacle-detection system.

The representative experimental results demonstrated a maximum speed of approximately 0.42 m/s on a smooth surface and approximately 3.1 hours of normal operating time. The solar panel produced a representative peak power of approximately 90.7 W under favorable sunlight conditions. The soil-moisture system successfully identified different moisture conditions, while the obstacle-detection system operated effectively within the tested range.

The system demonstrates that solar energy can be integrated with mobile robotics to reduce dependence on conventional energy sources while supporting agricultural monitoring and automation.

Future development involving GPS, IoT, machine vision, artificial intelligence, autonomous navigation, and robotic

agricultural tools can significantly increase the capability of the proposed system.

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