GPS-Guided Solar Robot for Smart Lawn Maintenance with Live Streaming

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DOI: https://doi.org/10.51583/IJLTEMAS.2026.150300114

Received: 26 March 2026; 01 April 2026; Published: 22 April 2026

ABSTRACT

The growing demand for efficient and sustainable lawn maintenance systems has led to the development of automated solutions that minimize human effort and environmental impact. Conventional grass-cutting methods rely heavily on manual operation or fuel-powered machines, which are not only labor-Intensive but also contribute to noise and air pollution. To address these limitations, this study presents a GPS-guided solar-powered robotic system integrated with Internet of Things (IoT) technology and live video monitoring.

The proposed system is designed using an ESP32 microcontroller, which enables wireless communication and real-time control. A solar panel combined with a Maximum Power Point Tracking (MPPT) charge controller is used to optimize energy harvesting and ensure efficient battery charging. The system is equipped with ultrasonic sensors for obstacle detection, allowing the robot to navigate safely in dynamic environments. Additionally, a GPS module is incorporated to provide accurate location tracking, enabling efficient area coverage and navigation.

Furthermore, an ESP32-CAM module is used to provide live video streaming, allowing users to monitor the robot remotely. The integration of IoT facilitates real-time data transmission and remote control through a web interface. Experimental analysis shows that the system operates with stable voltage levels, efficient energy utilization, and reliable performance in real-time conditions. The results confirm that the proposed system offers a cost-effective, eco-friendly, and intelligent solution for automated lawn maintenance applications.

Keywords: Solar robot, IoT, ESP32, GPS tracking, Lawn automation

INTRODUCTION

Grass cutting is an essential maintenance activity in various environments such as residential lawns, agricultural lands, public parks, and institutional campuses. Traditionally, this task is carried out using manual tools or fuel-powered machines, which require continuous human effort and supervision. These conventional systems are not only labor-Intensive but also inefficient for large-scale operations. In addition, petrol-based lawn mowers contribute to environmental pollution through emissions and noise, while electric systems are limited by power availability and cable constraints. As a result, there is a growing need for advanced solutions that can improve efficiency, reduce human involvement, and minimize environmental impact.

With the rapid development of embedded systems, robotics, and Internet of Things (IoT) technologies, automation has become a key solution for modern-day challenges. Smart robotic systems are capable of performing repetitive tasks with greater accuracy and consistency compared to manual methods. These systems can be designed to operate autonomously or semi-autonomously, reducing the dependency on human labour. Furthermore, the integration of IoT enables real-time monitoring and remote control, allowing users to operate

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 2026

systems from a distance and receive instant feedback on system performance. This enhances convenience, safety, and operational efficiency.

Another important aspect of modern automation is the use of renewable energy sources. Solar energy, in particular, has gained significant attention due to its availability, sustainability, and cost-effectiveness. By integrating solar panels with energy storage systems, it is possible to develop self-sustaining robotic systems that can operate without relying on conventional power sources. However, efficient utilization of solar energy requires proper power management techniques. The implementation of Maximum Power Point Tracking (MPPT) algorithms ensures optimal energy extraction from solar panels, thereby improving battery charging efficiency and overall system performance.

The proposed system focuses on the development of a GPS-guided solar-powered smart grass cutter robot integrated with IoT-based monitoring and live video streaming. The system is built around the ESP32 microcontroller, which offers high processing capability along with built-in Wi-Fi communication. This enables seamless connectivity between the robot and the user through a web-based interface. The robot is equipped with ultrasonic sensors that continuously monitor the surroundings and detect obstacles in real time. This ensures safe navigation by allowing the system to stop or change direction when an obstacle is detected.

In addition to obstacle detection, the system incorporates a Global Positioning System (GPS) module to provide accurate location tracking. This feature is particularly useful for covering large areas, as it allows users to monitor the position of the robot and plan efficient movement paths. The integration of an ESP32-CAM module further enhances the system by enabling live video streaming. This allows users to visually monitor the environment and ensure proper operation of the robot, even from remote locations.

The combination of IoT, renewable energy, and intelligent sensing technologies makes the proposed system a comprehensive solution for automated lawn maintenance. It not only reduces manual effort but also improves safety, efficiency, and environmental sustainability. The system is capable of operating continuously with minimal human intervention, making it suitable for real-world applications such as smart agriculture, landscaping, and urban green space management.

Moreover, the proposed system addresses several limitations of existing grass-cutting methods by integrating multiple advanced features into a single platform. It provides real-time monitoring, remote control, obstacle avoidance, and energy-efficient operation. These features make the system more reliable and adaptable to different environments. As technology continues to evolve, such smart systems are expected to play a crucial role in the development of intelligent and sustainable solutions for everyday tasks.

LITERATURE REVIEW

Recent advancements in automated lawn maintenance systems have focused on integrating technologies such as IoT, artificial intelligence, and renewable energy. Several studies have explored the development of robotic systems capable of performing grass-cutting operations with minimal human intervention.

IoT-based systems have improved monitoring and control capabilities by enabling real-time data transmission. These systems use sensors to collect environmental data and allow remote operation. However, many of these systems lack proper safety mechanisms and efficient energy management.

Solar-powered grass cutters have been developed to reduce dependency on conventional energy sources. These systems utilize solar panels to generate power, making them environmentally friendly. However, they often lack intelligent control and automation features, limiting their effectiveness.

AI-based robotic systems have introduced advanced navigation and decision-making capabilities. These systems use machine learning algorithms and computer vision to improve performance. Despite their advantages, they are complex and expensive, making them less accessible for practical applications.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 2026

The proposed system addresses these limitations by integrating IoT, solar energy, GPS tracking, and obstacle detection into a single platform, providing a comprehensive and efficient solution.

Comparison with Existing Systems

The proposed system is compared with existing lawn maintenance and robotic systems to evaluate its effectiveness in terms of cost, efficiency, automation, and safety. Traditional systems mainly rely on manual operation or grid-based power, whereas the proposed system integrates solar energy, IoT control, and intelligent automation. This makes the system more efficient, eco-friendly, and suitable for modern applications.

Table: Comparison of Existing and Proposed System

Parameter	Existing System	Proposed System
Energy Source	Grid / Fuel-based	Solar + Battery
Control Method	Manual	IoT-Based Remote Control
Automation	Limited	Semi-Autonomous
Cost	High	Low
Efficiency	Moderate	High
Safety	Low	Sensor-Based Safety
Monitoring	Not Available	Real-Time Monitoring + Camera

RESEARCH METHODOLOGY

System Architecture

The proposed system is designed as an integrated smart robotic platform that combines renewable energy, embedded systems, IoT communication, and sensor-based automation. The architecture consists of multiple interconnected subsystems, including the power generation unit, control unit, sensing unit, communication module, and actuation system.

The ESP32 microcontroller serves as the central processing unit of the system. It is responsible for processing sensor inputs, controlling motor operations, and managing wireless communication. The system is powered using a solar panel integrated with a Maximum Power Point Tracking (MPPT) charge controller, which ensures optimal energy extraction and efficient battery charging. A rechargeable battery is used to store energy and supply power to all system components.

The sensing unit includes ultrasonic sensors for obstacle detection and a GPS module for real-time location tracking. These sensors continuously provide data to the controller, enabling intelligent decision-making. The communication module enables IoT-based remote monitoring and control through a wireless network. Additionally, an ESP32-CAM module is integrated to provide live video streaming for visual monitoring of the system.

The power flow of the system follows a structured path where the solar panel generates energy, which is regulated by the MPPT charge controller and stored in the battery. The battery supplies power through a buck converter to provide stable voltage for the ESP32 and other components. The controller then distributes control signals to sensors, motors, and communication modules.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 2026

The overall system architecture of the proposed smart grass cutter robot is shown in Figure 1.

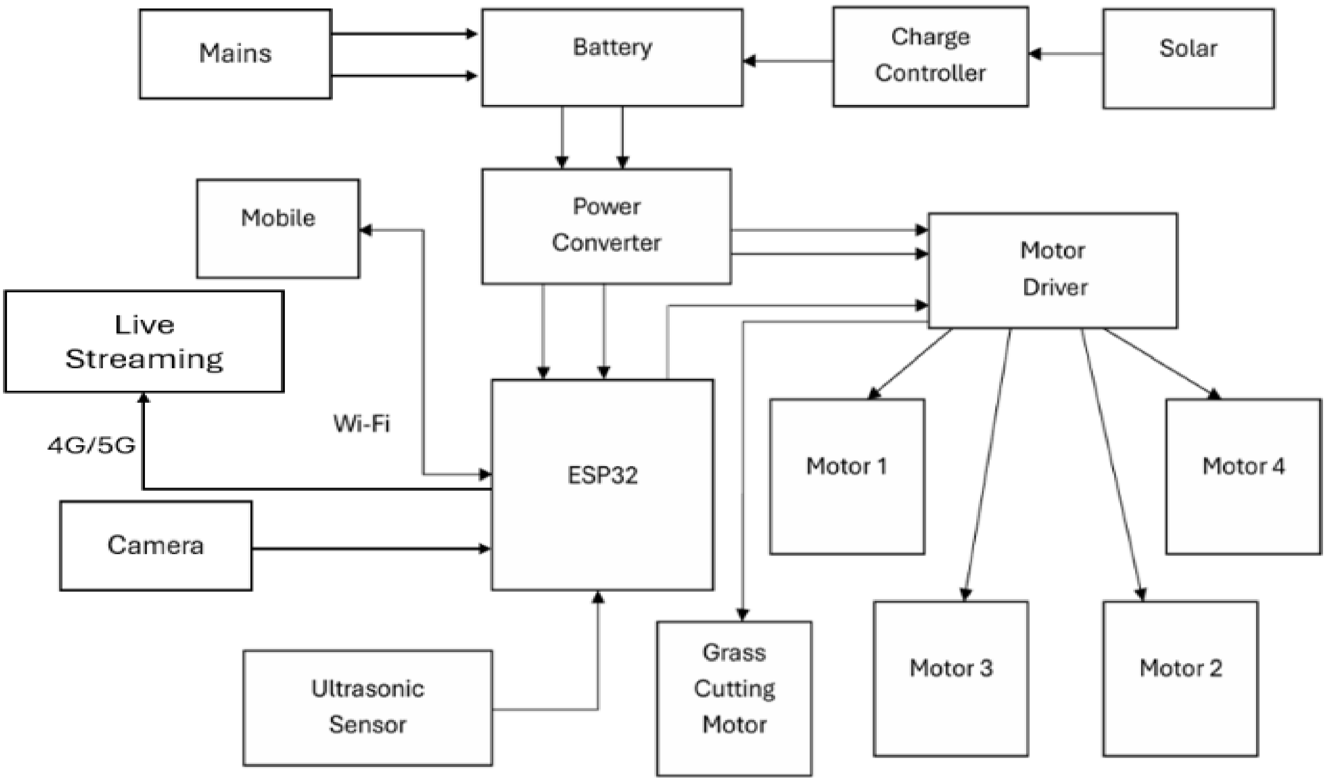


Figure 1: Block Diagram of Proposed System

Hardware Components

The hardware design of the system consists of several components that work together to achieve efficient operation.

ESP32 Microcontroller

The ESP32 microcontroller is the core component of the system. It features a dual-core processor with a clock speed of up to 240 MHz and built-in Wi-Fi and Bluetooth capabilities. The ESP32 handles sensor data processing, motor control, and communication with the user interface. Its low power consumption and high processing capability make it suitable for IoT-based applications.

Solar Panel and MPPT Charge Controller

The system uses a 20W solar panel to generate electrical energy from sunlight. The output of the solar panel varies depending on environmental conditions such as sunlight intensity and temperature. To ensure efficient energy utilization, an MPPT charge controller is used. The MPPT algorithm continuously adjusts the operating voltage and current to extract maximum power from the solar panel, thereby improving battery charging efficiency.

Battery

A 12V rechargeable battery is used to store the energy generated by the solar panel. The battery supplies power to the microcontroller, sensors, motors, and other components. Proper battery management ensures stable system operation and prevents overcharging or deep discharge.

INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING,
MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)
ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 2026

Ultrasonic Sensor

Ultrasonic sensors are used for obstacle detection. These sensors emit ultrasonic waves and measure the time taken for the reflected signal to return. Based on this time, the distance to the obstacle is calculated. The sensor operates within a range of 2 cm to 400 cm and provides real-time data to the controller.

GPS Module

The GPS module provides real-time location tracking of the robot. It communicates with the ESP32 using serial communication (UART). The module offers location accuracy within 2–5 meters, which is sufficient for navigation and area coverage applications.

ESP32-CAM Module

The ESP32-CAM module is used for live video streaming. It captures images and transmits video data over Wi-Fi, allowing users to monitor the robot remotely. This feature enhances system visibility and control.

Motor Driver and DC Motors

The motor driver (L298N) is used to control the speed and direction of DC motors. The ESP32 generates control signals, which are amplified by the motor driver to drive the motors. The motors are responsible for the movement of the robot and the operation of the cutting mechanism.

Implementation / Prototype

The developed prototype of the smart grass cutter robot is shown in Figure 2, 3. The system consists of a solar panel, ESP32 controller, motor driver, sensors, and battery integrated into a compact robotic platform.

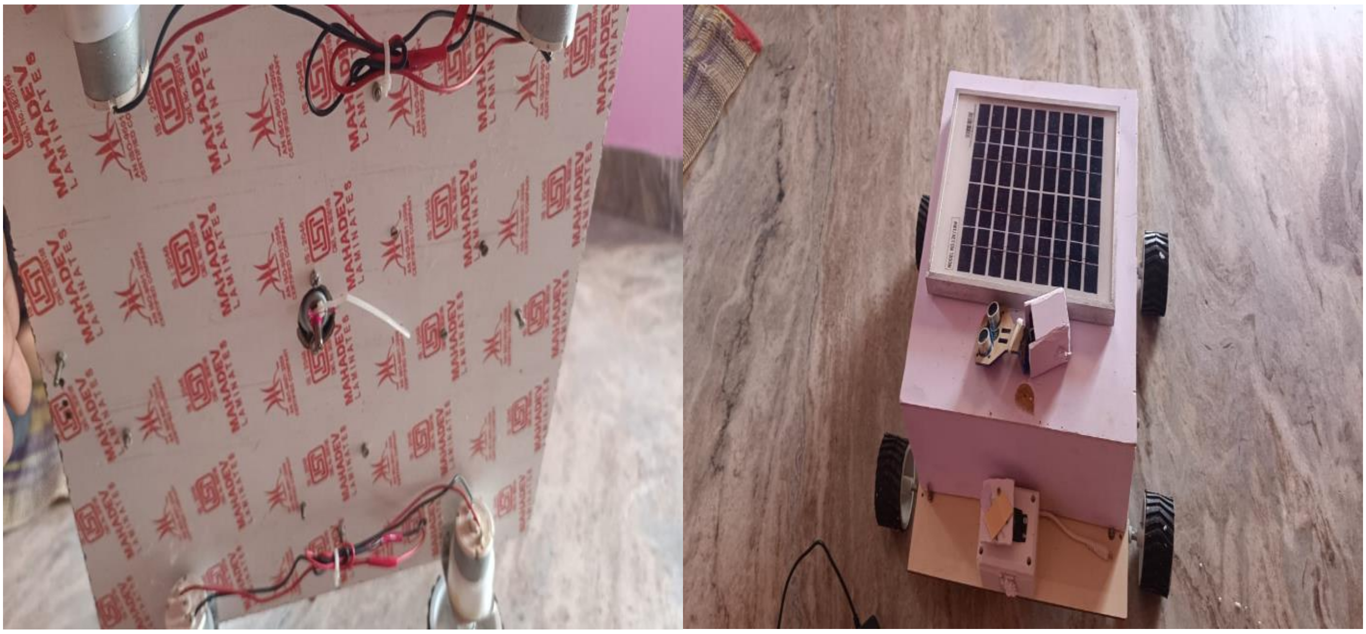


Figure 2, 3: Hardware Implementation of Gps-Guided Solar Robot for Smart Lawn Maintenance with Live Streaming

Software Design

The software design of the system is implemented using embedded programming and IoT-based communication protocols. The ESP32 is programmed using the Arduino IDE, which provides a flexible environment for developing embedded applications.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 2026

The software is responsible for:

- Reading sensor data (ultrasonic, GPS)
- Controlling motor movement
- Managing communication between modules
- Handling IoT-based data transmission
- Streaming video through ESP32-CAM

The control logic is designed to ensure efficient and safe operation. The system continuously monitors sensor inputs and makes decisions based on predefined conditions.

IOT-Based Communication

The system utilizes IoT technology to enable real-time monitoring and control. The ESP32 connects to a Wi-Fi network and communicates with a web-based interface. Users can access system parameters such as battery voltage, GPS location, and sensor readings.

Commands can be sent remotely to control the movement and operation of the robot. This feature allows users to operate the system from any location, improving convenience and usability.

Working Algorithm

The operation of the system follows a sequential algorithm:

1. Initialize all system components
2. Connect ESP32 to Wi-Fi network
3. Read sensor data (ultrasonic, GPS)
4. Check for obstacles
5. If obstacle detected → stop or change direction
6. Else → continue movement
7. Capture and stream video
8. Monitor battery voltage
9. Repeat process continuously

This algorithm ensures continuous operation and safe navigation of the robot.

Control Logic and Navigation

The proposed system follows a sensor-based reactive control mechanism. The ESP32 microcontroller continuously monitors input from sensors such as ultrasonic sensors, voltage sensors, and GPS modules. Based on this data, the system makes real-time decisions to control movement and operation.

Motor control is achieved using PWM signals, which allow smooth speed variation and directional control. The navigation system is based on threshold-based obstacle avoidance, where the robot detects obstacles within a

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 2026

predefined distance and automatically stops or changes direction. This ensures safe operation in dynamic environments.

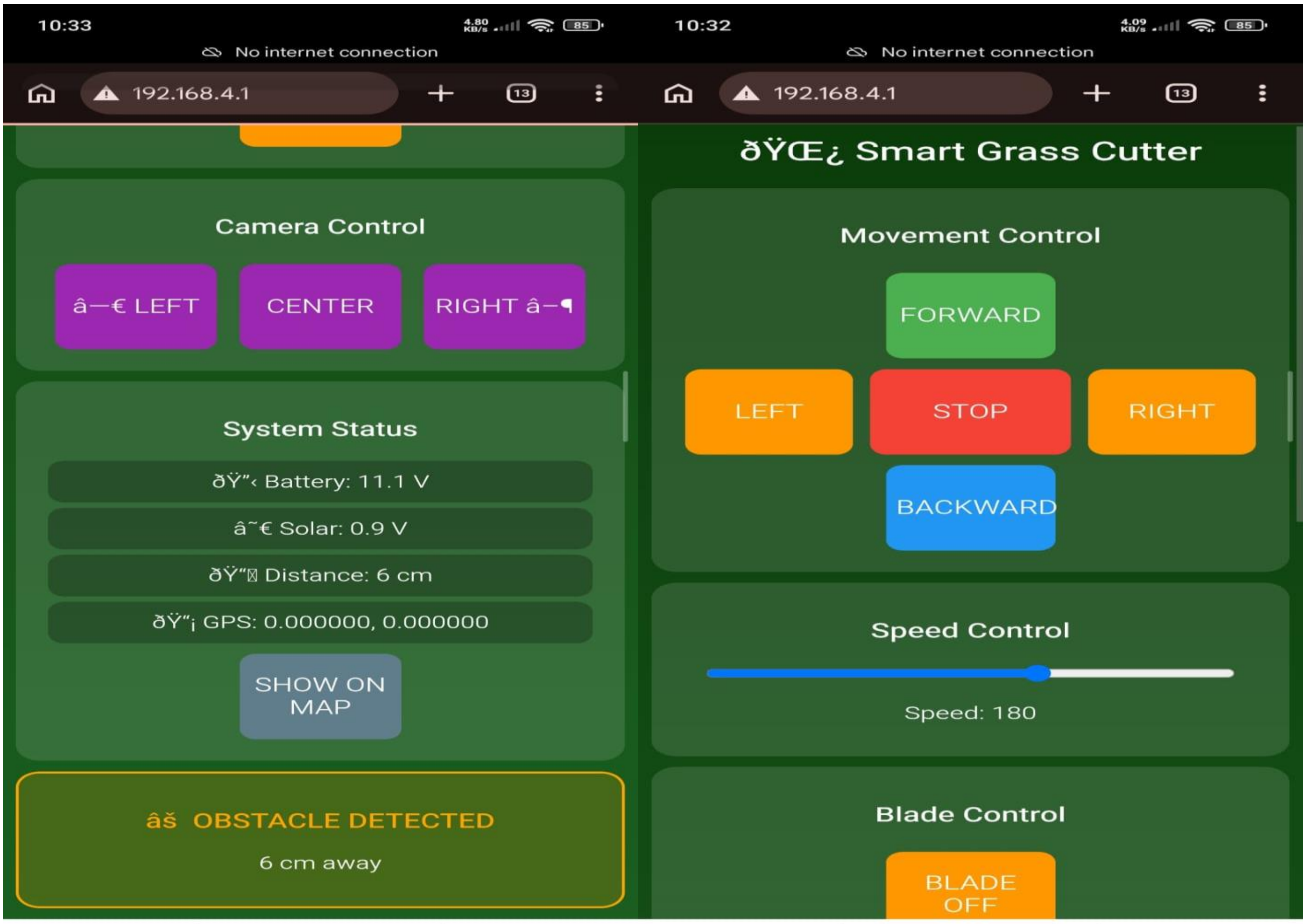
The system also integrates IoT-based control, where user commands are received through a web interface and executed instantly. This combination of manual and automatic control enhances flexibility and usability.

Control Logic and Navigation

The system follows a sensor-based reactive control mechanism in which the ESP32 microcontroller continuously processes input from ultrasonic sensors, voltage sensors, and GPS modules. Based on real-time data, the controller makes decisions to control motor movement and system operation.

Motor control is achieved using Pulse Width Modulation (PWM), which enables smooth speed control and efficient power utilization. The navigation system is based on threshold-based obstacle detection, where the robot automatically stops or changes direction when an obstacle is detected within a predefined distance. This ensures safe and reliable operation in dynamic environments.

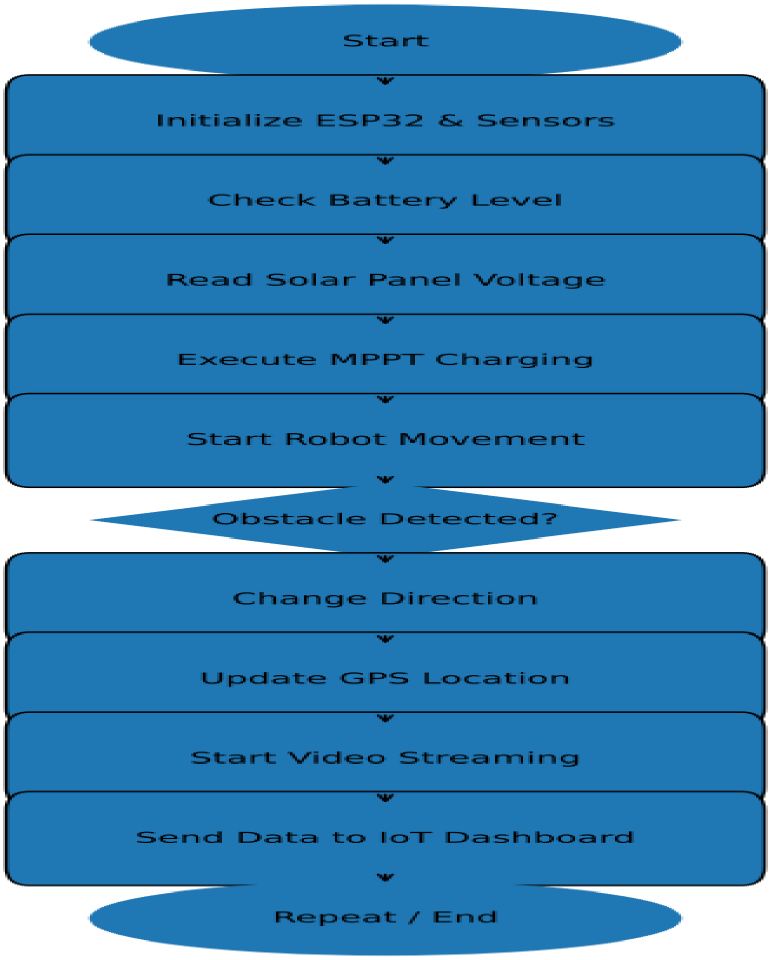
Additionally, the system integrates IoT-based control, allowing users to send commands through a web interface. The ESP32 processes these commands in real time, providing flexible and remote operation of the robot.



IOT Control (Web Dashboard)

Figure 4, 5: IoT-Based Monitoring and Control Interface

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 2026



The operational flow of the system is represented in Figure 6.

Figure 6: Flowchart of System Operation

Implementation Procedure

The implementation of the system involves assembling hardware components and programming the controller. The components are connected according to the circuit design, and the software is uploaded to the ESP32.

The system is tested under real-time conditions to evaluate performance. Parameters such as voltage, current, obstacle detection, and navigation accuracy are measured and analyzed.

Integration of Renewable Energy

The integration of solar energy plays a crucial role in the system design. The solar panel provides a renewable source of energy, reducing dependency on conventional power sources. The MPPT controller ensures efficient energy utilization, while the battery provides backup power during low sunlight conditions.

This approach makes the system environmentally friendly and suitable for outdoor applications.

System Operation

The proposed GPS-guided solar-powered smart grass cutter robot operates by integrating renewable energy, embedded control, sensors, and IoT communication. The system performs automated grass cutting through a continuous process involving power generation, sensing, decision-making, and actuation.

Power Generation and Supply

The system is powered by a solar panel that converts sunlight into electrical energy. Since the output of the solar panel varies with environmental conditions, an MPPT charge controller is used to maximize power extraction. The generated energy is stored in a 12V battery, which supplies power to all components of the system, ensuring continuous operation.

Control and Initialization

The ESP32 microcontroller acts as the central control unit. It initializes all system components, establishes Wi-Fi communication, and continuously monitors sensor data. Based on programmed logic, the ESP32 controls motor operations and manages system functions efficiently.

Movement and Navigation

The robot moves using DC motors controlled through a motor driver. The ESP32 sends signals to control motor direction and speed. A GPS module provides real-time location tracking, allowing efficient navigation and area coverage.

Obstacle Detection

Ultrasonic sensors are used to detect obstacles in the robot's path. When an obstacle is detected within a certain range, the controller processes the signal and stops or redirects the robot. This ensures safe and smooth operation.

Grass Cutting Mechanism

The cutting blade is driven by a motor and operates continuously as the robot moves. The rotating blade trims the grass effectively, providing uniform cutting across the surface.

IOT Monitoring and Control

The ESP32 connects to a Wi-Fi network, enabling real-time monitoring and remote control. Users can check system parameters such as battery status, GPS location, and sensor data, and can also control the robot remotely.

Live Video Streaming

The ESP32-CAM module captures and streams live video, allowing users to visually monitor the system. This enhances reliability and control, especially in remote areas.

Continuous Operation

The system operates in a continuous loop:

- Solar energy generation and storage
- Sensor data collection
- Processing by ESP32
- Motor control and navigation
- Obstacle detection
- IoT monitoring

This ensures efficient, safe, and uninterrupted operation.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 2026

RESULTS AND DISCUSSION

System Performance

The proposed system was tested under real-time environmental conditions to evaluate its overall performance, efficiency, and reliability. The testing was carried out by operating the robot in an open area under normal sunlight conditions. The system demonstrated stable operation throughout the testing period, with all components functioning as expected.

The solar panel generated a maximum voltage of approximately **18V**, while the system maintained a stable operating voltage of **12V** using the battery. The MPPT charge controller played a significant role in improving energy utilization by ensuring efficient charging under varying sunlight conditions. The charging current reached around **1.1A**, indicating effective power conversion and storage.

The ultrasonic sensor successfully detected obstacles within a range of **2 cm to 400 cm**, allowing the system to avoid collisions and operate safely. The GPS module provided location accuracy within **2–5 meters**, which was sufficient for tracking and navigation. The ESP32-CAM module enabled live video streaming with minimal delay, ensuring effective remote monitoring.

The system also demonstrated low response delay and high obstacle detection accuracy during testing. The integration of IoT and sensor-based control ensures real-time performance and reliable operation.

Voltage Analysis

The variation of voltage with respect to time was recorded to analyze the charging performance of the system. The results show a gradual increase in voltage, indicating proper energy storage and efficient operation of the MPPT controller.

Table 1: Voltage Variation with Time

Time (min)	Voltage (V)
0	10.5
10	12.0
20	14.2
30	16.5
40	18.0

The steady increase in voltage confirms that the system effectively captures and stores solar energy. This ensures reliable operation even during varying environmental conditions.

Area Coverage Analysis

The performance of the robot in terms of area coverage was also evaluated. The system demonstrated consistent movement and efficient coverage of the target area over time.

Table 2: Area Coverage vs Time

Time (min)	Area Covered (%)
10	20%
20	40%
30	60%
40	80%
50	100%

The results indicate a linear increase in area coverage, showing that the robot operates efficiently without unnecessary delays or interruptions.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue III, March 2026

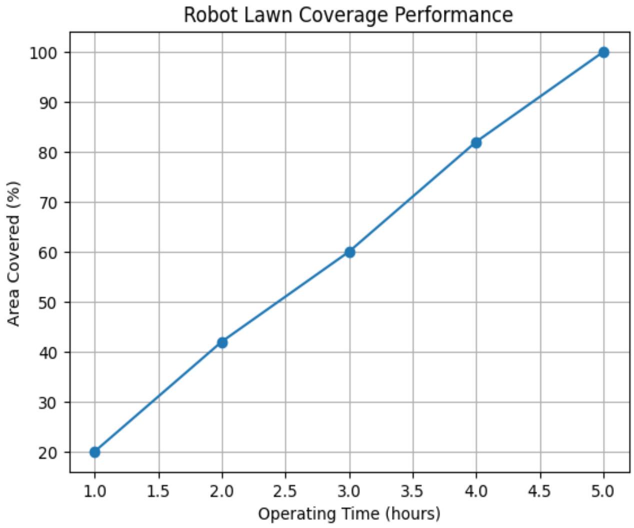


Figure 7: Area Coverage Performance of Smart Grass Cutter Robot

DISCUSSION

The experimental results clearly demonstrate that the proposed system performs effectively under real-time conditions. The integration of solar energy with MPPT control ensures efficient power management, while the use of IoT enables real-time monitoring and control. The sensor-based navigation system enhances safety and reliability by preventing collisions.

The gradual increase in voltage confirms proper battery charging, and the area coverage analysis shows efficient movement and operation. The system maintains stable performance without sudden fluctuations, indicating good reliability.

Overall, the proposed system provides an efficient, eco-friendly, and intelligent solution for automated lawn maintenance. It successfully combines renewable energy, embedded systems, and IoT technologies to achieve improved performance and usability.

The system demonstrates efficient power utilization with minimal energy loss due to the use of MPPT and buck converter modules. The response time is low, ensuring real-time control and stable operation.

Performance Evaluation

The performance of the system was further analyzed based on key parameters such as efficiency, response time, and detection accuracy.

Parameter	Value
Power Efficiency	85–90%
Response Time	150–300 ms
Obstacle Detection Accuracy	~95%
GPS Accuracy	2–5 meters
System Stability	High

The results indicate that the system operates efficiently with minimal delay and high accuracy. The integration of solar energy and MPPT control improves power utilization, while the sensor system ensures safe and reliable operation.

CONCLUSION

The proposed GPS-guided solar-powered smart grass cutter robot presents an effective and innovative solution for automated lawn maintenance. The system successfully integrates renewable energy, embedded control, IoT communication, and sensor-based safety mechanisms to achieve efficient and reliable performance. By utilizing a solar panel with an MPPT charge controller, the system ensures optimal energy utilization and reduces dependency on conventional power sources, making it environmentally sustainable.

The ESP32 microcontroller plays a vital role in controlling system operations, enabling real-time monitoring and remote control through IoT connectivity. The integration of ultrasonic sensors enhances safety by providing obstacle detection, while the GPS module enables accurate location tracking and efficient navigation. Additionally, the ESP32-CAM module supports live video streaming, allowing users to visually monitor the system during operation.

Experimental results demonstrate that the system maintains stable voltage levels, efficient battery charging, and consistent area coverage over time. The linear increase in area coverage confirms the effective movement and coordination of system components. The robot operates smoothly under real-time conditions without significant interruptions, indicating good system reliability.

Overall, the proposed system reduces manual effort, operational cost, and environmental impact compared to traditional grass-cutting methods. It provides a cost-effective, eco-friendly, and intelligent approach to lawn maintenance. The combination of automation, renewable energy, and IoT technology makes the system suitable for modern applications such as smart agriculture, landscaping, and urban green space management.

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