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Design and Implementation of an AI and IoT Enabled Solar-Powered Robotic Lawn Mower

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Abstract— **The increasing demand for sustainable and autonomous lawn maintenance systems has accelerated the development of intelligent robotic solutions. This paper presents the design and implementation of an AI and IoT based solar-powered robotic lawn mower capable of autonomous navigation, grass cutting, and waste collection. The proposed system utilizes renewable solar energy combined with a rechargeable battery to ensure eco-friendly and energy-efficient operation. An ESP32 microcontroller manages motor control, navigation, and obstacle avoidance, while a Raspberry Pi 4 handles intelligent decision-making and robotic arm operation for waste collection.**
Ultrasonic sensors are employed for real-time obstacle detection, ensuring safe and adaptive movement across outdoor environments. A robotic arm equipped with a high-torque servomotor is integrated to detect and collect plastic waste, enhancing environmental cleanliness. IoT connectivity enables real-time monitoring of system status, battery level, and operational control through a web-based interface.

Experimental evaluation demonstrates improved lawn coverage, reduced redundant motion, and efficient power utilization. The integration of solar energy significantly reduces dependence on conventional power sources, making the system cost-effective and environmentally sustainable. The results confirm that AI-driven navigation and IoT-based monitoring enhance operational reliability and user convenience. This work highlights the potential of intelligent robotic systems in sustainable lawn maintenance applications.

Keywords— Robotic lawn mower, Solar-powered system, Artificial intelligence, Internet of Things, Autonomous navigation.

I. INTRODUCTION

With advancements in technology, the demand for efficient, sustainable, and autonomous solutions for daily tasks has surged. One area where these innovations can have a significant impact is lawn maintenance, where traditional methods can be labor intensive, costly, and environmentally taxing. The development of a solar-powered robotic lawn mower, integrated with AI and IoT capabilities, presents a compelling solution.

This project aims to design and implement a smart, solar-powered robotic lawn mower that operates autonomously. Equipped with IoT sensors and advanced AI algorithms, the mower can optimize its path, avoid obstacles, and adapt to changing environmental conditions. Solar power provides an eco-friendly energy source, ensuring that the mower can operate sustainably without relying on non-renewable energy.

The combination of AI and IoT allows the mower to communicate with other smart devices, receive real-time weather and lawn condition updates, and adjust its operation accordingly. This project not only addresses the need for an efficient lawn-care solution but also contributes to reducing carbon footprints by utilizing renewable energy.

II. LITERATURE REVIEW

A. *Review of Existing Systems*

Several studies have explored the development of automated and solar-powered lawn maintenance systems to reduce manual effort and environmental impact. Kirubha et al. [1]

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proposed a smart lawn mower that uses embedded controllers and obstacle detection sensors to enable autonomous operation. While the system improved safety and reduced human intervention, it relied on conventional power sources, limiting its sustainability.

Tahir et al. [2] presented an IoT-based solar-powered lawn mower that enables remote monitoring and control through a web interface. The integration of solar energy significantly reduced dependence on grid power, and IoT connectivity enhanced user convenience. However, the system lacked advanced intelligence for optimized path planning and adaptive decision-making.

Shah et al. [3] developed a solar-powered intelligent grass cutter robot using an Arduino microcontroller and ultrasonic sensors for obstacle avoidance. Although the system demonstrated effective grass cutting and basic automation, it required manual control through Bluetooth, reducing its level of autonomy.

Sri et al. [4] proposed an IoT-based solar grass cutting robot with remote control features and sensor-based navigation. While the system successfully combined renewable energy with automation, it did not address environmental waste management or intelligent navigation strategies.

From the existing literature, it is evident that most systems focus primarily on automated grass cutting and energy efficiency. Limited attention has been given to integrating AI-based navigation, autonomous waste collection, and real-time IoT monitoring within a single system. The proposed work addresses these gaps by combining AI-driven decision-making, solar-powered operation, IoT-based monitoring, and a robotic arm for environmental waste collection.

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B. Research Gap and Limitations of Existing Systems

From the review of existing literature, it is observed that although several automated and solar-powered lawn mower systems have been developed, certain limitations still remain. Most existing systems focus mainly on basic automation and energy efficiency, with limited implementation of intelligent decision-making and adaptive navigation.

Many reported designs rely on simple microcontrollers and sensor-based obstacle avoidance without incorporating AI-based path planning or learning capabilities. Additionally, while IoT connectivity has been introduced in some systems for remote monitoring, real-time system intelligence and autonomous control are often limited.

Furthermore, environmental waste management has received minimal attention in previous works. The integration of features such as autonomous plastic waste detection and collection using robotic arms is rarely addressed. These limitations highlight the need for a more intelligent, eco-friendly, and multifunctional lawn maintenance system. The proposed work aims to address these gaps by integrating AI-driven navigation, solar-powered operation, IoT-based monitoring, and autonomous waste collection.

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III. METHODOLOGY

This section describes the design and implementation of the proposed solar-powered robotic lawn mower system. It outlines the system architecture, key hardware components, and control strategy used to achieve autonomous navigation, grass cutting, and waste collection. The interaction between the control units, sensors, and power management system is also briefly explained.

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A. Overview of Approach

The proposed system is a solar-powered, IoT-enabled smart lawn mower designed to autonomously perform grass cutting while also identifying and collecting plastic waste using a robotic arm. The mower harnesses solar energy to charge its batteries, promoting sustainable operation without relying on external power sources. A microcontroller acts as the central control unit, interfacing with various sensors for obstacle detection and navigation. Machine learning algorithms enable the detection of plastic bottles, triggering the robotic arm to collect the object.

B. Hardware Components and Setup

Solar panel: To ensure continuous and sustainable operation, the robotic lawn mower integrates a high-efficiency solar panel system designed to harness solar energy during daylight hours. The solar panel generates sufficient power to operate the mower while also charging a dedicated rechargeable battery system.

Control Units (ESP32 & Raspberry Pi): The ESP32 and Raspberry Pi 4 work together as the core controllers of the AI and IoT-based solar lawn mower. The ESP32 handles motor control for wheel movement, the cutting mechanism, and blade height adjustment using PWM signals and sensor feedback for obstacle detection and terrain adaptation. It also allows manual or automatic height control via a mobile app. Meanwhile, the Raspberry Pi 4 manages the robotic arm, using camera and sensor data to detect plastic bottles and control the arm's precise movements for collection. It also supports AI-based decision- making and real-time communication with the ESP32 and IoT interface. This combined setup ensures intelligent navigation, efficient grass cutting, and autonomous waste removal. The Raspberry 2 Pi and ESP32 communicate through UART serial communication. The Raspberry Pi performs AI- based processing and transmits control commands to the ESP32, which handles motor control, obstacle avoidance, and IoT communication. Both devices operate at 3.3V logic levels, ensuring safe and reliable data transfer.

MG995 servomotor: The MG995 servomotor is integrated into the robotic arm for its high torque, precise control, and durability—making it ideal for gripping and lifting plastic bottles in outdoor environments. Operating at 6V with a response speed of 0.16 seconds per 60 degrees, it enables quick and accurate positioning, essential for reliable object handling. Its metal gear construction ensures long-term strength and resistance to wear, particularly in repetitive outdoor tasks. Mounted strategically within the robotic arm for optimal load distribution, the MG995 is controlled through predefined voltage thresholds without relying on AI or sensors, simplifying the system while maintaining effective and dependable performance.

Propulsion Motor: A 12V DC motor is used for the lawn mower's movement due to its high torque and ability to handle various terrains effectively. With a speed of 100 RPM, it ensures smooth, controlled motion suitable for outdoor use. It is easily managed through a motor driver for precise speed and direction control and integrates well with the 12V lithium-ion battery, offering reliable and efficient propulsion for the mower's autonomous operation.

Lithium -Ion Battery: A 12V lithium-ion (Li- ion) battery was chosen as the primary power source due to its compact size, lightweight nature, and stable voltage output. With a capacity of 1200mAh and current rating of 1.2A, it provides sufficient power for both the motors and control circuits. By connecting three cells in series, an output of approximately 11.1V is achieved— ideal for the system's requirements. Li-ion batteries offer a favorable energy-to-weight ratio, are rechargeable, and support consistent performance, making them well-suited for portable, outdoor applications. For propulsion, a 12V DC motor operating at 100 RPM was selected for its high torque and reliability across various terrains. Controlled via a motor driver, it allows for precise speed and direction control, integrating smoothly with the battery system to ensure efficient and stable movement of the autonomous lawn mower.

Voltage Regulator: To ensure a stable and efficient power supply for various system components, two voltage regulation solutions were incorporated: the LM317 adjustable voltage regulator and the LM2596 DC-DC buck converter. The LM317 is used to step down and regulate the voltage from the solar panel, providing a controlled and adjustable output suitable for charging the battery and powering essential circuits. This ensures that sensitive components, such as the ESP32 microcontroller and control modules, receive a steady and reliable 12V supply. Additionally, the LM2596 buck converter is implemented to efficiently convert the 12V unregulated DC input to a stable 5V output, minimizing heat generation and improving overall system efficiency. This regulated 5V output is essential for powering low-voltage components such as the ESP32, sensors, and servomotors, ensuring stable operation and protecting them from potential overvoltage damage. The combined use of these regulators enhances system stability, improves power management, and ensures the reliable operation of all electronic components.

Ultrasonic Sensors: Ultrasonic sensors can be effectively utilized in lawn mowers for object detection and obstacle avoidance, addressing the challenge of navigating through outdoor environments filled with various obstacles. These sensors emit high-frequency sound waves, measuring the time it takes for the waves to reflect back after hitting an object, thus determining the distance to nearby obstacles. By placing sensors around the mower, it can continuously scan its surroundings, providing real-time data for the mower's control system. This data helps the mower decide whether to stop, change direction, or adjust its path to avoid collisions.

Robotic Arm: The robotic arm is incorporated into the system to enable autonomous collection of plastic waste during lawn maintenance operations. Its primary function is to detect, grasp, and remove lightweight objects such as plastic bottles from the lawn area, thereby enhancing environmental cleanliness. The arm is actuated using a hightorque servomotor, allowing precise positioning and controlled movement for reliable object handling. By integrating the robotic arm with the control system, the lawn mower achieves dual functionality—grass cutting and waste collection—reducing the need for manual intervention and improving overall operational efficiency.

C. Block Diagram

The block diagram illustrates the overall architecture of the proposed solar-powered robotic lawn mower system. The solar panel serves as the primary energy source and charges the battery, which supplies power to the system through a voltage regulation unit to ensure stable operating voltages.

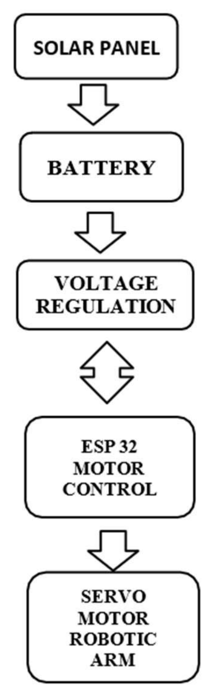

Fig 1. Block diagram

The regulated power is provided to the ESP32 microcontroller, which acts as the main control unit for motor operation and sensor interfacing. The ESP32 controls the propulsion motors through motor drivers and also operates the servo motor used in the robotic arm for waste collection. Sensors are connected to the ESP32 for obstacle detection and navigation, while advanced processing modules such as the AI camera and GPS are interfaced with the Raspberry Pi for intelligent decision-making. Communication between the control units is established using UART, enabling coordinated operation of navigation, cutting, and waste collection functions.

IV. RESULTS AND DISCUSSION

The proposed solar robotic lawn mower uses AI and IoT technology for a sustainable and self-sufficient way to maintain lawns. It effectively combines renewable energy with smart control and IoT monitoring. The solar-powered design cuts down on the need for traditional energy sources. AI navigation helps the mower avoid obstacles and cover the lawn efficiently. IoT connectivity makes the system easier to use by allowing real-time monitoring and remote control. Tests show that the propulsion system, robotic arm, and power management work reliably outdoors. This system reduces the need for manual work, boosts energy efficiency, and supports eco-friendly lawn care.

Overall, the experimental results demonstrate that the proposed system achieves reliable autonomous operation under real outdoor conditions. The coordinated functioning of the control units, sensors, and power management system ensures stable performance with minimal human intervention. The integration of a robotic arm for waste collection further enhances the system's practical usefulness by combining lawn maintenance with environmental cleanliness.

V. FUTURE SCOPE

Future work may focus on implementing advanced AI-based path optimization to improve coverage efficiency and minimize redundant motion. Enhanced terrain adaptability can be achieved through improved mobility and sensing mechanisms for uneven surfaces. The use of higher-capacity energy storage and more efficient solar panels can extend operational duration. Vision-based object detection using camera systems and deep learning models may further enhance obstacle and waste identification accuracy.

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