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Integration of Solar Energy and Embedded Control for Autonomous Grass Cutting Robots

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Abstract

This paper presents the design and development of a solar-powered autonomous grass cutting robot with obstacle detection and avoidance capabilities. The system utilizes solar energy as its primary power source, reducing reliance on conventional charging and minimizing environmental impact. At its core, the Arduino Uno development board, based on the Atmega328p microcontroller, performs all control and computational tasks. An ultrasonic sensor enables real-time obstacle detection, allowing the robot to adjust its path dynamically and avoid collisions. The motor driver circuit translates microcontroller signals into precise wheel movements, ensuring smooth navigation and efficient area coverage. Control algorithms are programmed in a simplified C++ environment using the Arduino IDE. The integration of solar energy, embedded control, and intelligent navigation provides an eco-friendly, cost-effective, and sustainable solution for automated lawn care. Experimental results validate effective performance under varying conditions, demonstrating strong potential for residential and institutional applications.

Keywords: Solar-powered robot, Grass cutting system, Autonomous lawn mower, Arduino Uno, Atmega328p microcontroller, Ultrasonic sensor, Obstacle detection and avoidance, Renewable energy in robotics, Embedded control system, Sustainable automation.

1. Introduction

In recent years, the need for sustainable and autonomous solutions in lawn maintenance has become increasingly critical, driven by growing environmental concerns, labor cost pressures, and the push towards renewable energy adoption. Traditional petrol-based grass cutters contribute significantly to air pollution, noise, and fossil fuel dependency, while requiring frequent maintenance and input energy. Consequently, research has focused on integrating solar power, embedded control, and sensor-based obstacle avoidance to develop eco-efficient robotic mowers. One example is “Solar Powered Grass Cutter for Domestic Utilization”, which utilized the Arduino Uno to control dual DC gear motors and achieved over two hours of operation when fully charged [1]. Another project, “Implementation of an IoT-Based Solar-Powered Smart Lawn Mower”, combined solar panels, Arduino Uno for energy management, Raspberry Pi for remote control, and achieved sustainable, networked operation [2]. The “Arduino Based

Smart Solar Mower" specifically integrated ultrasonic sensors for obstacle detection and demonstrated practical usability in solar automated mowing tasks [3]. In addition, the study "An IoT Based Obstacle Avoidance Robot Using Ultrasonic Sensor and Arduino" focused on using ultrasonic sensors along with Arduino control to navigate around obstacles in real time [4]. Despite such work, many systems still suffer from limited obstacle avoidance, lack of full solar autonomy, or constrained power management. For example, the "Development and Evaluation of Efficient Smart Solar Lawn Mower" examined the effects of different grass types on battery voltage drop, noting performance variability under load [5]. The "Design of Automated Solar Lawn Mover" incorporated Arduino Uno, ultrasonic sensors, and motor driver circuits for wheel motion, striving for a fully autonomous solar-powered vehicle [6]. A more economical approach was shown in "Development of an Economical Solar Powered Lawn Mover", which focused on cost reduction while maintaining basic solar battery driven cutting functions [7]. Further, "Development and Performance Evaluation of Solar Powered Lawn Mower" conducted field trials on large working torques using BLDC motors and solar energy sources [8]. Earlier foundational works include "Design and Development of a Solar Powered Lawn Mower", which laid out basic hardware architecture combining solar panels, rechargeable battery banks, DC motors, and control switches [9]. Surveys such as "Survey on Solar Powered Lawn Mower Robot" provide a comparative framework for the hardware, power, and control trade-offs across various designs [10].

Problem Statement: Though the prior literature presents promising designs, many grass-cutting robots still depend on partial external power, lack dynamic obstacle avoidance robustness, or manage solar power inefficiently under varying environmental conditions. Therefore, there remains a need to design a robot that combines solar-only operation (with battery buffering), precise obstacle detection and avoidance, and an embedded control logic that optimizes energy usage in real time.

Objectives: This research aims to:

1. Design a grass-cutting robot powered primarily by solar energy, ensuring competent battery storage to maintain operation under partial sun, optimizing solar panel specification.
2. Integrate ultrasonic obstacle detection for real-time avoidance, enabling safe and continuous navigation in varied outdoor environments.
3. Employ an embedded control system based on Arduino Uno (Atmega328p), along with a motor driver circuit for wheel actuation and continuous control flow implemented in Arduino-friendly C++.
4. Conduct thorough performance evaluation: runtime under sunlight, obstacle avoidance accuracy, power consumption vs solar input, and coverage effectiveness.

SYSTEM DESIGN AND METHODOLOGY:

The design and implementation of the proposed solar-powered grass cutting robot involved hardware selection, circuit design, and software development. The methodology is divided into four major parts: hardware design, circuit description, software implementation, and system flow.

A. Design Hardware:

The robot is built around an **Arduino Uno** (ATmega328P) microcontroller as the central processing unit. Major components include:

1. **Power Subsystem**

Solar Panel: 12 V / 20 W photovoltaic module, used as the primary energy source.

Charge Controller: Regulates charging and prevents overcharging of the **12 V rechargeable battery**, which stores harvested energy.

Battery: Supplies stable power to both the control electronics and drive motors.

2. **Sensing Subsystem**

Ultrasonic Sensor (HC-SR04): Provides real-time obstacle detection with a range of 2–400 cm.

3. **Actuation Subsystem**

Wheel Motors: Two 12 V geared DC motors for robot movement.

Cutter Motor: High-torque DC motor for the grass-cutting blade.

Motor Driver (L298N): Dual H-bridge driver used to control both wheel and cutter motors under Arduino commands.

Mechanical Structure:
The chassis is fabricated from lightweight aluminum and acrylic sheets. The solar panel is mounted on the top surface, serving as both an energy harvester and a protective cover.

B. Circuit Description: The **block diagram** of the system is shown in **Fig. 1**.

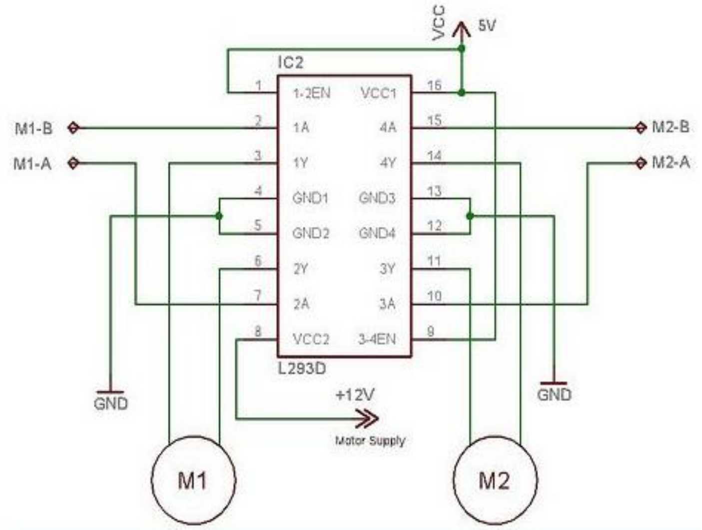

Fig. 1. Block diagram of the solar-powered grass cutting robot

The solar panel charges the battery through a charge controller. The battery powers both the Arduino Uno and the motor driver circuit. The Arduino receives input from the ultrasonic sensor and generates control signals for the motor driver, which drives the wheel and cutter motors.

C. Software Implementation

The control logic was implemented using the Arduino IDE in C++ language. The main functions are:

1. **Initialization:** Configure pins for sensors and motors.
2. **Sensing:** Continuously read distance from the ultrasonic sensor.
3. **Decision Making:**

If distance > threshold → robot moves forward.

If distance ≤ threshold → robot stops, reverses, and turns.

4. **Actuation:** Generate PWM signals to motor driver for movement.
5. **Cutting Action:** Cutter motor remains ON during operation.

D. System Flow

The **software flowchart** is presented in **Fig. 2**. The robot begins by initializing all components. The ultrasonic sensor continuously monitors obstacles. If no obstacle is detected, the robot moves forward while the cutter motor remains active. When an obstacle is detected, the robot halts, reverses, and changes direction before resuming forward motion. This loop continues until the battery is depleted or the system is manually stopped.

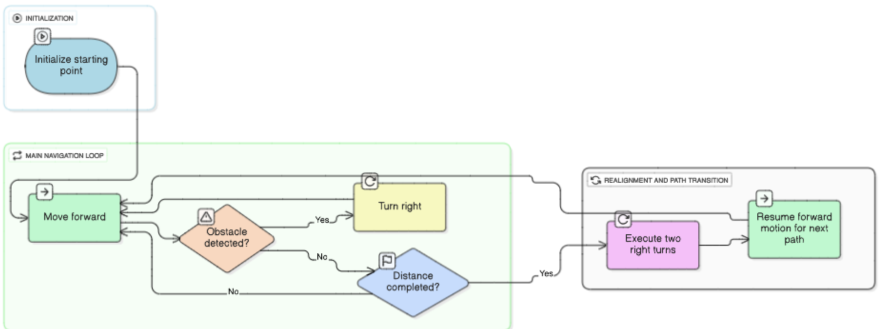

Fig. 2. Software flowchart of the grass cutting robot

EXPERIMENTED HARDWARE PROTOTYPE: Ultrasonic sensors emit short, high-frequency sound pulses at regular intervals. These propagate in the air at the velocity of sound. If they strike an object, then they are reflected as echo signals to the sensor, which itself computes the distance to the target based on the timespan between emitting the signal and receiving the echo. The global push toward sustainable technologies have created an increased demand for energy-efficient automation systems. Grass cutting, a mundane yet labor-intensive activity, is one such area where automation has been adopted. Conventional grass cutting machines are generally powered by fossil fuels or direct electricity, leading to environmental concerns and high operational costs. Autonomous grass cutting robots, when integrated with renewable energy sources such as solar power, can provide a clean, cost-effective, and efficient solution for maintaining lawns, parks, and agricultural lands.

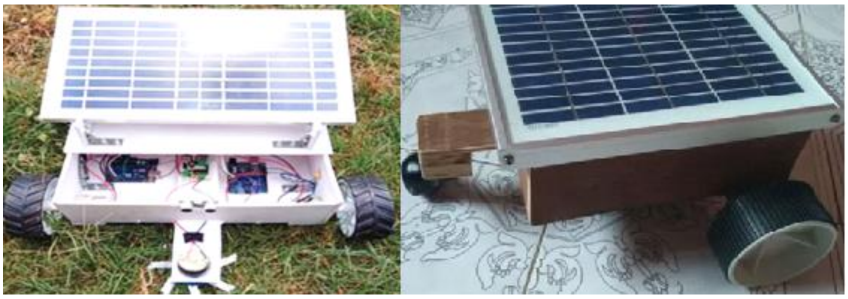

Fig. 3. Hardware Prototype Unit

This work presents the design and development of a hardware prototype for an autonomous grass cutting robot powered by solar energy and governed by an embedded control system. The prototype demonstrates how solar energy can be harvested and utilized to run a grass-cutting mechanism while ensuring autonomy through sensor integration and microcontroller-based decision-making. The hardware prototype was constructed on a 40 cm × 35 cm aluminum frame. The solar panel was mounted at the top with an adjustable angle to maximize sunlight exposure. Wheels of 15 cm diameter provided sufficient ground clearance for uneven lawn surfaces. The grass-cutting blade was positioned at the center bottom of the chassis, driven by a 12V DC motor.A compact PCB housed the Arduino Uno, motor driver, and charge controller. The sensors were placed strategically – ultrasonic sensors at the front for obstacle detection, and IR sensors near the base for boundary recognition. The wiring was organized to minimize interference and ensure modularity.

Conclusions

The integration of solar energy with embedded control for autonomous grass cutting robots represents a step forward in sustainable automation. The hardware prototype developed in this study demonstrates the feasibility of using solar-powered embedded systems for real-world lawn maintenance tasks. By reducing reliance on conventional fuels, lowering operational costs, and providing autonomous functionality, such robots can significantly contribute to eco-friendly and efficient outdoor maintenance. Although challenges remain in terms of energy management, navigation efficiency, and scalability, the prototype provides a strong foundation for further research and development. Future advancements integrating artificial intelligence, advanced navigation systems, and hybrid power solutions will enhance the practicality of solar-powered autonomous grass cutting robots, making them a viable solution for both domestic and commercial applications.

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