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Solar-Powered Vacuum Cleaner and Floor Cleaning Robot: A Review of Energy-Efficient Robotic Cleaning Systems

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Abstract - The increasing demand for automated cleaning solutions has encouraged the development of intelligent robotic systems capable of reducing manual effort and improving cleaning efficiency. Conventional vacuum cleaners and floor-cleaning robots primarily depend on electrical energy supplied through rechargeable batteries, which require periodic charging from external power sources. Integrating solar energy into robotic cleaning systems offers a potential approach to improving energy sustainability and reducing dependence on grid electricity. This review paper examines the design principles, technologies, and applications of a solar-powered vacuum cleaner and floor-cleaning robot. The proposed system combines a photovoltaic panel, rechargeable battery, microcontroller, motor driver, suction mechanism, floor-mopping unit, and obstacle-detection sensors. Solar energy is converted into electrical energy and managed through a suitable charging and power-regulation circuit. A microcontroller coordinates robot movement, obstacle avoidance, vacuum operation, and floor-cleaning functions. The paper reviews relevant technologies, compares existing cleaning approaches, and discusses the benefits and limitations of solar-assisted robotic cleaning. Particular attention is given to energy management, cleaning performance, navigation, system cost, and practical implementation. The proposed concept is suitable for small indoor spaces, laboratories, offices, and educational demonstrations. Solar assistance may improve energy utilization when adequate sunlight is available, although indoor photovoltaic performance and the limited surface area of a mobile robot remain important design challenges.

Key Words: Solar energy, robotic vacuum cleaner, floor cleaning robot, photovoltaic panel, Arduino, obstacle avoidance.

1. INTRODUCTION

Cleaning is an essential activity in residential buildings, educational institutions, hospitals, laboratories, and commercial spaces. Conventional cleaning methods require manual effort and consume time, particularly when large floor areas must be maintained regularly. Robotic cleaning systems offer an alternative by combining mechanical movement, electronic control, and cleaning mechanisms in a compact platform.

A robotic vacuum cleaner typically uses a suction motor and brushes to collect dust, while a floor-cleaning robot may use a water pump, mop, or rotating brush to remove surface dirt. Combining these mechanisms in a single robot can provide dry and wet cleaning capabilities.

Solar photovoltaic technology converts sunlight into electrical energy. In a solar-assisted cleaning robot, a photovoltaic panel can supply energy to a charging circuit or rechargeable battery. The stored energy can then power the control electronics, drive motors, and cleaning mechanisms. However, the solar panel mounted on a small robot has limited surface area, so a solar charging station or external photovoltaic panel may be more practical for sustained operation.

Recent work on solar-powered floor-cleaning robots has explored microcontrollers, ultrasonic sensors, wireless communication, and automated cleaning functions. A 2023 study titled Solar Floor Cleaner Robot describes a renewable-energy-based cleaning machine, while a 2026 study examines an IoT-enabled autonomous floor-cleaning robot. These works demonstrate relevant approaches to integrating solar power and embedded control.

The objective of this review is to examine the major technologies involved in a combined solar-powered vacuum cleaner and floor-cleaning robot, identify their limitations, and propose a practical architecture suitable for a student engineering project.

2. Body of Paper

2.1 Overview of Solar-Powered Robotic Cleaning Systems

Solar-powered robotic cleaning systems combine renewable energy technology with automated cleaning mechanisms to reduce manual effort and improve energy utilization. These systems generally consist of a mobile chassis, a power supply unit, a microcontroller, motor drivers, sensors, and a cleaning assembly. The proposed solar-powered vacuum cleaner and floor cleaning robot integrates dry dust collection and wet floor cleaning into a single robotic platform. A photovoltaic panel provides electrical energy for battery charging, while the battery supplies the power required for movement, suction, and mopping operations.

The integration of solar energy with robotic cleaning technology requires careful consideration of power consumption, battery capacity, mechanical design, and cleaning efficiency. Unlike stationary solar-powered equipment, a mobile cleaning robot has limited space for mounting photovoltaic panels. Therefore, solar energy can be used as a supplementary power source, while a rechargeable battery provides the primary operating power.

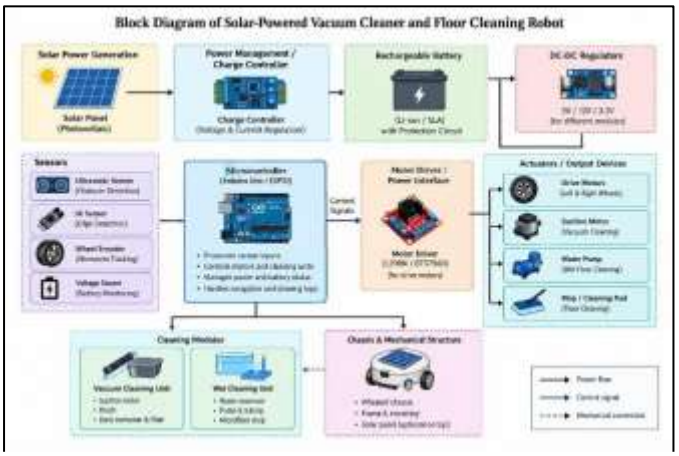


Fig: Block Diagram

2.2 Hardware Description

The hardware of the proposed system consists of electronic components, mechanical assemblies, power-supply circuits, sensors, and cleaning mechanisms. These components work together to perform automated dry vacuum cleaning and wet floor cleaning using a microcontroller-based control system with solar-assisted battery charging.

2.2.1 Hardware Components and Their Functions

1. Arduino Uno

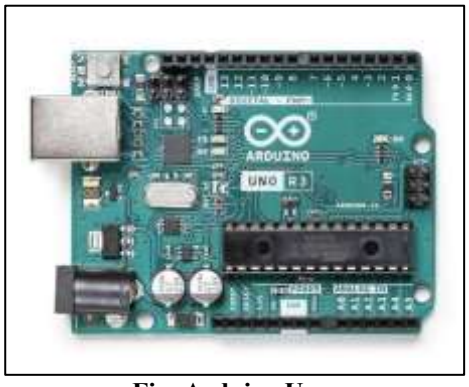


Fig: Arduino Uno

The microcontroller acts as the central control unit of the robot. It receives signals from sensors, processes the information, and generates control signals for the drive motors, vacuum motor, and water pump. Arduino Uno is suitable for basic control, while ESP32 offers additional wireless connectivity.

2. Solar Photovoltaic Panel



Fig: Solar Photovoltaic Panel

The solar panel converts sunlight into DC electrical energy. This energy is used to charge the rechargeable battery through a compatible charge controller. Panel output depends on sunlight intensity, panel rating, temperature, and orientation.

3. Rechargeable Battery and Protection Circuit

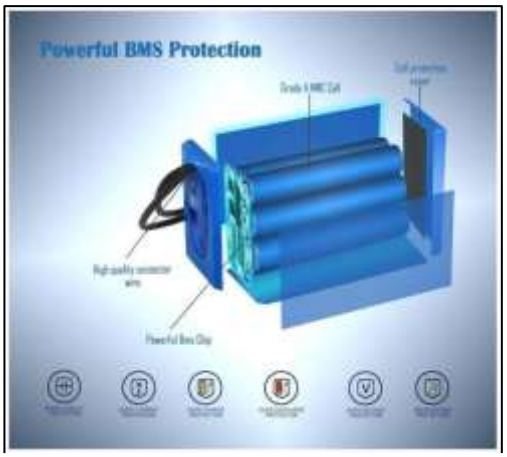


Fig: Rechargeable Battery and Protection Circuit

The battery stores electrical energy for operating the robot when solar energy is unavailable. A suitable protection circuit helps prevent overcharging, excessive discharge, and overcurrent. The battery voltage and current ratings must match the motors and electronic circuits.

4. Ultrasonic Sensor



Fig: Ultrasonic Sensor

The ultrasonic sensor measures the distance between the robot and an obstacle by transmitting ultrasonic waves and measuring their return time. The microcontroller uses this information to stop the robot or change its direction to avoid collisions.

5. Motor Driver Module

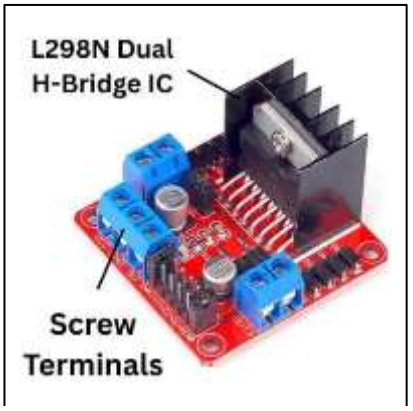


Fig: Motor Driver Module

The motor driver provides the current required by the DC drive motors and enables forward, reverse, and turning movements.

An L298N module can be used for small educational prototypes if its current and thermal ratings are adequate. Higher-current motors require a suitably rated driver.

6. DC Geared Motors and Wheels



Fig: DC Geared Motors and Wheels

The geared motors drive the robot across the floor. Two independently controlled drive motors can provide differential steering, allowing the robot to move forward, reverse, and turn. Wheels and chassis dimensions should provide adequate traction and stability.

7. Vacuum Suction Motor



Fig: Vacuum Suction Motor

The suction motor creates airflow to collect dust and small particles from the floor. It works with an air inlet, brush, dust container, and filter. The motor should be selected according to the required suction performance and available battery capacity.

8. DC Water Pump and Reservoir



Fig: DC Water Pump and Reservoir

The water pump delivers a controlled quantity of water from the reservoir to the wet-cleaning mechanism. A switching circuit controlled by the microcontroller can start and stop the pump as required. The water system must be isolated from the electronics.

9. Microfiber Mop / Cleaning Pad



Fig: Microfiber Mop / Cleaning Pad

The microfiber pad removes surface dirt and fine residues during wet cleaning. It is attached to the underside or rear of the robot and should be removable for washing and maintenance.

10. DC–DC Voltage Regulator



Fig: DC–DC Voltage Regulator

The regulator converts the battery voltage to suitable levels for the controller, sensors, and other electronic modules. Separate power paths for high-current motors and control electronics can reduce electrical noise and improve system stability.

2.2.2 Mechanical Structure

The mechanical structure consists of a chassis, mounting frame, wheels, suction inlet, dust collection container, water reservoir, and mop assembly. The chassis supports all components and must maintain balanced weight distribution. The vacuum inlet should be positioned close to the floor, while the mop assembly should be arranged to prevent water from entering the suction unit or electrical compartment.

2.2.3 Power Supply and Electrical Connections

The solar panel is connected to a compatible solar charge controller, which charges the battery according to the battery manufacturer's specifications. The battery supplies the motor drivers, suction mechanism, water pump, and regulated controller supply. All modules must use compatible voltage levels and suitable wiring, fuses, and connectors.

High-current motors must not be connected directly to the Arduino or ESP32 GPIO pins. Appropriate motor drivers or switching circuits should be used, with a common signal ground where required by the circuit design.

2.3 Software Description

The software controls the operation of the robot, processes sensor information, manages cleaning functions, and responds to obstacles. The proposed system can be programmed using the Arduino IDE with C/C++-based embedded programming.

2.3.1 Arduino IDE

The Arduino IDE is used to write, compile, and upload the program to the microcontroller. It provides libraries for interfacing with sensors and supports digital output control, PWM motor control, and serial monitoring for debugging.

2.3.2 Embedded C/C++ Programming

The control program defines the robot's operating sequence and the logic for motor movement, obstacle detection, vacuum operation, and water-pump control. The program is divided into initialization, sensor reading, decision-making, actuator control, and safety monitoring.

2.3.3 Sensor Interfacing

The software reads distance measurements from the ultrasonic sensor and evaluates whether an obstacle is within a specified threshold. Optional infrared or cliff sensors can provide additional safety information. Sensor readings should be validated to reduce false obstacle detections.

2.3.4 Motor Control Algorithm

The program sends direction and speed commands to the motor driver. Under normal conditions, the robot moves forward. When an obstacle is detected, the controller stops the motors and commands a turn before resuming movement. PWM can be used to adjust motor speed when supported by the selected driver.

2.3.5 Vacuum and Wet-Cleaning Control

The software activates the vacuum motor during dry cleaning and operates the water pump during wet cleaning. A selectable cleaning mode can enable vacuum-only, mop-only, or combined operation. For safety, dry vacuuming before wet mopping is a suitable default sequence. Wet cleaning should be disabled when the battery is below the permitted operating threshold or when an unsafe condition is detected.

2.3.6 Battery Monitoring and Solar Charging

A voltage-monitoring circuit can provide battery status to the microcontroller. The software can reduce cleaning activity or stop the robot when the battery voltage falls below a defined threshold. Solar charging should be managed by a charge controller compatible with the battery chemistry; the microcontroller should not be used as a substitute for the required charging and battery-protection circuitry.

2.3.7 Flow of Software Operation

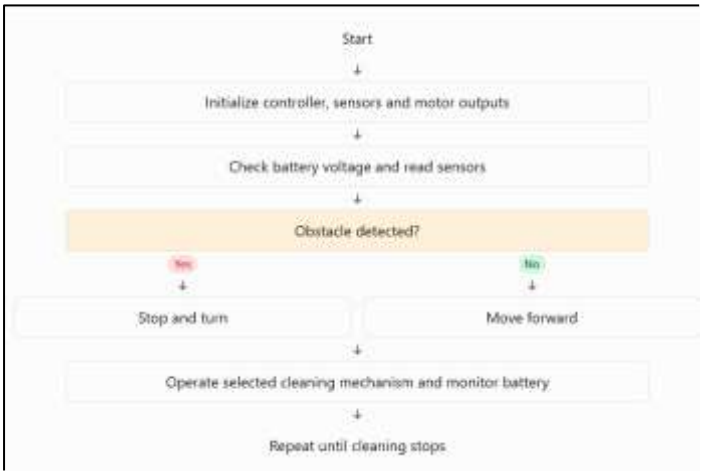


Fig: Software flow of the proposed robotic cleaning system.

3. CONCLUSIONS

The hardware provides the physical movement, energy supply, sensing, and cleaning capabilities of the robot, while the software coordinates these components to achieve automated operation. Integrating a photovoltaic charging system with battery-powered cleaning mechanisms can support more sustainable energy use. The reliability of the complete system depends on suitable component selection, correct electrical interfacing, effective control logic, and experimental validation of cleaning performance and energy consumption.

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