SOLAR POWERED SOLAR PANEL CLEANING ROBOT

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ABSTRACT

Solar panel efficiency decreases due to dust, dirt, and environmental contaminants, especially in arid regions. Manual cleaning is labor-intensive and unsafe for large installations. This project presents a **solar-powered solar panel cleaning robot** that maintains panel performance using a rechargeable battery charged by the solar panels. The robot uses **dual ultrasonic sensors** for obstacle detection and fall prevention, and **dual IR sensors** near the front edge for accurate edge detection. A NodeMCU (ESP32) controls the robot's movement via an L298N motor driver for forward, reverse, and turning. A 2-channel relay module controls the brush motor and water pump, spraying water at timed intervals from an onboard tank. The system reduces manual maintenance, improves energy output, and enhances safety in residential and large-scale solar installations.

I. INTRODUCTION

Solar energy has become one of the most prominent renewable energy sources due to its abundance, sustainability, and low environmental impact. The global shift toward clean energy has accelerated the deployment of solar photovoltaic (PV) systems in residential, commercial, and industrial sectors. Solar panels are commonly installed on rooftops, open fields, and solar farms to harness sunlight and convert it into electricity. However, the efficiency of solar panels is significantly affected by environmental factors such as dust, dirt, pollen, bird droppings, and industrial pollution. These contaminants accumulate on the panel surface, forming a layer that reduces the amount of sunlight reaching the PV cells. In arid and semi-arid regions, the rate of dust accumulation is particularly high, causing substantial losses in energy output. The decrease in efficiency not only reduces power generation but also impacts the economic feasibility of solar installations.

Regular cleaning of solar panels is therefore essential to maintain their performance. Manual cleaning methods are widely used, but they are labor intensive,

time-consuming, and often unsafe, especially for large rooftop installations or

extensive solar farms. Manual cleaning also requires water and human resources, which can increase operational costs. Moreover, in large solar farms, accessing every panel for cleaning is impractical and may lead to inconsistent maintenance schedules. Therefore, there is a need for an automated cleaning solution that can operate autonomously, reduce maintenance costs, and improve the overall efficiency of solar systems.

II.   LITERATURE SURVEY

[1] Satish patil, Mallaradhya H M (2016) design and implementation of microcontroller based automatic dust cleaning system for solar panel. international journal of engineering research and advanced technology (ijerat) issn: 2454-6135 special volume. 02 issue.01, may-2016 conditions with the deposition of the unique pollutants like ash, sand, silica, calcium carbonate and crimson soil. Later retaining the PV model cool and clean, effects are acquired for effective device presentation. The strength generation in each instances become experimentally determined. Sooner or later by way of the use of the above said computerized cleaning scheme the power output can be expanded approximately 30%, as compared to other cleansing technologies. Also, recurrent periodic cleansing guarantees that the panel works with true conduction step by step.

[2] Shaharin A. Sulaiman ``Effects of Dust on the Performance of PV Panels` International Journal of Mechanical, Aerospace, Industrial, Mechatronics and Manufacturing Engineering Vol:5, 2011 Dust accumulation from the outside environment on the solar photovoltaic (PV) panels system is natural. There were studies which showed that the accumulated dust can minimize the performance of solar panels, but the results were not evidently quantified. The purpose of this research was to study the dust accumulation effects and then analyze the performance of solar PV panels. Experiments were conducted by utilizing dust particles on solar panels with a steady power light source, to conclude the resulting electrical power generated and efficiency. The effect of presence of dust was studied using artificial dust (mud and talcum) under a constant irradiance conducted in an indoor lab. Dust has consequences on the solar PV panel performance. The decline in the peak power generation can be equal to 18%. It was also given away that under larger irradiation; the effect of dust became somewhat minimized but not negligible.

[3] Ali Omar Mohamed, Abdulazez Hasan, "Effect of Dust Accumulation on Performance of Photovoltaic Solar Modules in Sahara Environment" Journal of Basic and applied scientific Research, Volume 2, Issue11, Pages 11030-11036 The aim of this paper is to give an innovative concept to handle energy demand around the world is increasing rapidly for many applications. Renewable sources of energy are solar, wind and geothermal which are inexhaustible. Solar energy is abundant in nature and is proving its existence for many applications like

street lighting, house hold appliances, water heating, agricultural and industrial purpose. One of the ways to harness solar energy is done by using solar panels. Limitation of solar energy is its efficiency for any application due to the factors like dust, humidity, temperature etc. Electrical parameters of solar panel are sensitive to accumulated dust density and will affect the transmittance of the solar panel thereby reduce its efficiency. In order to overcome this problem, it is necessary to clean the solar panels regularly.

III.   SYSTEM ARCHITECTURE

The system architecture of the Solar Powered Solar Panel Cleaning Robot describes how all hardware blocks are connected and work together. The main power source is the solar panel, which charges the battery through a charging and regulation circuit. The stored energy is used to operate the entire system.

A microcontroller acts as the brain of the system. It receives input signals from IR sensors and ultrasonic sensors, which are used to detect panel edges, obstacles, and safe movement paths. Based on sensor data, the microcontroller controls the robot's motion and cleaning process.

The motor driver is used to drive the DC motors for forward, reverse, and turning movements of the robot. A relay module controls the brush motor and water pump. The brush motor performs continuous cleaning, while the pump operates in a timed ON/OFF cycle to save water.

All components work in coordination to ensure automatic, safe, and efficient cleaning of the solar panel surface without human intervention.

IV.   METHODS AND MATERIAL

[1] Solar Panel: Converts sunlight into electrical energy to power the system and charge the   battery.

[2] Rechargeable Battery (Li-ion Battery Pack): Stores electrical energy from the solar panel and supplies power to the robot.

[3] Battery Management System (BMS): Protects the Li-ion battery from overcharging, over-discharging, short circuit, and balancing issues.

[4] Microcontroller (ESP32): Acts as the brain of the robot. It controls all sensors, motors, and logic operations.

[5] Ultrasonic Sensors: Measure distance from obstacles. Used to detect objects ahead and maintain a safe distance.

[6] IR Sensors: Detect the edge of the solar panel. Prevent the robot from falling and help in direction change.

[7] DC Motors (2 Units – Track belt Motors): Provide movement to the robot (forward, reverse, left, right).

[8] Motor Driver Module (L298N / L293D): Controls the speed and direction of the DC motors using signals from the microcontroller.

[9] Relay Module (2-Channel Relay): Acts as an electrical switch to control high-power devices like pump and brush motor.

[10] Water Pump Motor: Sprays water on the solar panel surface for cleaning.

[11] Brush Motor: Rotates the cleaning brush continuously to remove dust and dirt from the panel.

[12] Cleaning Brush: Physically cleans the solar panel surface along with water spray.

[13] Chassis / Frame: Mechanical structure that holds all components together.

[14] Wheels/Tracks: Enable smooth movement of the robot on the solar panel.

[15] Power Regulator / Buck Converter: Steps down voltage to required levels (e.g., 5V or 3.3V) for sensors and controller.

[16] Connecting Wires and PCB: Provide electrical connections between all components.

V. HARDWARE DESCRIPTION

The hardware of the **Solar Powered Solar Panel Cleaning Robot** consists of power, control, sensing, and actuation components. A **solar panel** is used as the primary power source to charge the **battery**, which supplies energy to all components through a **DC–DC converter** for voltage regulation.

A **microcontroller** is used to control the complete operation of the robot. It processes sensor inputs and generates control signals for motors and relays. **IR sensors** are used for edge detection to prevent the robot from falling off the panel, while **ultrasonic sensors** are used to detect obstacles and ensure safe movement.

DC motors are used for robot movement and brushing action. A **motor driver module** interfaces between the microcontroller and motors, allowing direction and speed control. A **relay module** is used to switch the brush motor and water pump. The **water pump** helps in wet cleaning by spraying water in a controlled manner.

All hardware components are selected to make the system low-cost, reliable, and suitable for domestic solar panel installations.

VI. WORKING METHODOLOGY

The working of the **Solar Powered Solar Panel Cleaning Robot** starts when the system is powered ON using energy stored in the battery charged by the solar panel. The microcontroller initializes all sensors, motors, and relays before starting the cleaning operation.

The robot moves forward on the solar panel using DC motors controlled by the motor driver. **IR sensors** continuously monitor the panel edges to prevent the robot from falling, while **ultrasonic sensors** detect obstacles and help in safe navigation. When an edge or obstacle is

detected, the microcontroller changes the direction of movement.

The **brush motor** is kept in continuous operation to remove dust and dirt from the panel surface. The **water pump** operates in a timed ON and OFF cycle to reduce water consumption while ensuring effective cleaning. After completing the cleaning path, the robot stops automatically.

VII. BLOCK DIAGRAM OF SOLAR POWERWD SOLAR PANEL CLEANING ROBOT
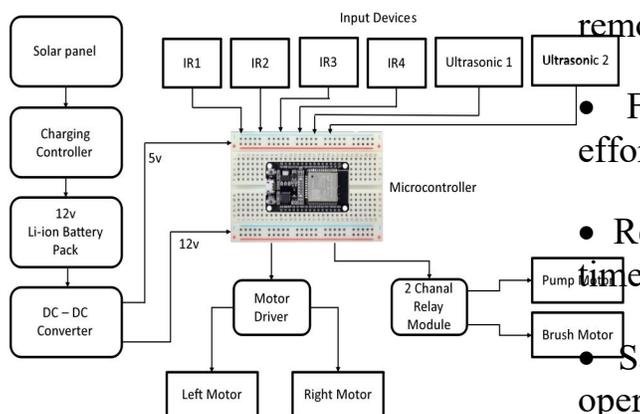
VIII. PROTOTYPE IMPLEMENTATION

IX. ADVANTAGES

• Improves solar panel efficiency by removing dust and dirt regularly

• Fully automatic operation, no human effort required

• Reduces maintenance cost and cleaning time

• Saves water by using controlled pump operation

• Safe operation with edge and obstacle detection

• Low power consumption and solar powered system

• Suitable for domestic and small-scale solar installations

X. APPLICATION

- Rooftop solar panel systems in residential buildings

- Small and medium-scale solar power plants

- Industrial solar panel installations

- Commercial buildings using solar energy

- Solar panels installed in remote or hard-to-reach areas

- Educational and research projects related to renewable energy and robotics

XI. RESULTS AND DISCUSSION

The cleaning robot was tested on a 500W solar panel. After cleaning, the panel's power output increased by **15-30%**, confirming improved efficiency. The dual ultrasonic sensors and IR sensors successfully prevented falls and detected edges, enabling safe movement. The NodeMCU control with L298N motor driver ensured stable motion and timed water spraying. The system operated autonomously for **1-1.5 hours** on a full battery charge. Water usage and battery capacity were the main limitations, suggesting a larger tank or higher capacity battery for longer cleaning. Overall, the robot effectively automates solar panel cleaning, enhances power generation, and improves safety.

1.Technological Advancements

- AI & Machine Learning: Smart cleaning algorithms can analyse dust patterns, predict cleaning schedules, and detect anomalies.

- Self-Sustaining charging, Cleaning: Solar-powered nanotechnology-based self cleaning coatings, and hybrid cleaning approaches (e.g., electrostatic, ultrasonic) will improve efficiency.

- IoT & Cloud Monitoring: Real-time performance tracking, SCADA integration, and advanced wireless connectivity will enhance remote monitoring.

- Robotics & Automation: AI-driven path planning, drone-based cleaning, and modular robot designs will optimize cleaning processes.

2. Market Expansion & Commercialization

- Utility-Scale Solar Farms: Demand for fully automated, large-scale solar cleaners will increase.

- Smart Cities & Smart Grids: Integration with smart infrastructure will improve power generation efficiency.

- Residential & Commercial Use: Affordable, compact cleaners will benefit homeowners and businesses.

- Emerging Markets: Developing regions with high solar potential will see rapid adoption, supported by government incentives.

3. Sustainability & Environmental Benefits

• Waterless Cleaning: Eco-friendly techniques like electrostatic and airflow-based cleaning will reduce water usage.

• Lower Carbon Footprint: Automated solutions will improve solar panel efficiency and reduce reliance on fossil fuels.

• Recycling & Sustainable Manufacturing: Future solar cleaners will use recyclable materials and introduce end-of-life recycling programs.

4. Challenges & Research Opportunities

• Adaptation to Various Panel Types: Developing solutions for tilted, floating, or vertical panels.

• Energy Efficiency: Innovations in battery technology (e.g., solid-state batteries, supercapacitors) to enhance efficiency.

• Affordability & Cost Reduction: Mass production, subsidies, and financing models will make solar cleaners more accessible.

These advancements will drive the future of solar panel maintenance, making it more efficient, cost effective, and environmentally friendly.

XII. CONCLUSION

The solar-powered autonomous cleaning robot presented in this project offers an effective and practical solution for maintaining solar panels in dusty and polluted environments. By combining dual ultrasonic and IR sensors, the robot ensures reliable edge detection, obstacle avoidance, and safe navigation across the panel surface. The NodeMCU-based control system efficiently manages the motor driver, brush, and water pump, enabling consistent cleaning cycles without human intervention. Test results demonstrate a significant improvement in panel performance, confirming that regular automated cleaning can enhance energy generation and overall system efficiency. Although the system's operation time is limited by battery capacity and water tank size, these challenges can be addressed by using higher-capacity batteries and larger tanks. Overall, the proposed design improves safety, reduces maintenance costs, and increases the longevity and output of solar PV systems, making it suitable for both residential and large-scale installations.

XIII. REFERENCES

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