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Solar Panel Automated Robot Cleaner for Optimal Solar Performance

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Abstract

Amongst the most important sustainable energy resources that offer us long-run economic benefits is solar energy. Nevertheless, it is observed that ac- cumulation of dust, sand, and defecation of birds on solar panels drastically af- fects the efficiency of solar panels by causing power loss due to the thin layer of dust that creates an invisible barrier in front of solar panels blocking the sunlight reaching it. The effect of this factor will be more severe if witnessed in highly polluted regions, construction sites, or desert areas where it will be essential to clean it by keeping it properly polished.

Methods for cleaning usually involve washing the panels with water. The meth- ods are labor-intensive, time-consuming, and pose a high risk to the people car- rying out the task, especially in high-altitude systems. Water cleaning methods are not suitable in arid regions that lack water. Large-scale cleaning methods are ineffective using human cleaning.

In an attempt to solve this problem, this study presents an autonomous solar panel cleaning robot which is safe, efficient, and eco-friendly. Through the application of microfiber rotating brushes, the dry cleaning process of the robot ensures the removal of accumulated dust particles from the surface of the solar panel, and this makes the robot applicable to different geographical locations. For the pur- pose of ensuring safety while the robot operates on an inclined or elevated sur- face, infrared sensors aid in the detection of the edges. The robot has a recharge- able battery. The robot operates in an efficient manner, thus reducing human in- terference, and this makes the robot applicable for use on a large scale.

Keywords: Solar Photovoltaic Systems; Automated Cleaning Robot; Dry Cleaning Mechanism.

How to Cite This Article

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Introduction

One of the most viable and commonly used sources of renewable energy all over the world is solar energy. The effect of the cleanliness of the surface of the solar panels on the efficiency of the photovoltaic cell has been found to be quite significant. Dust ac- cumulation in the solar panels causes a thin layer of dust, reducing the efficiency of solar energy and resulting in a reduction of up to 30% to 40% in areas of extreme dust pollution.

The conventional method for maintenance of solar panels involves the use of water- based cleaning methods/wipe cleaning. The method is not appropriate for large solar power systems, especially in regions where water is not abundant. Additionally, con- sidering that dust accumulation continuously affects the systems, it should be noted that photovoltaic systems operating in regions characterized by high sand and dust levels tend to experience intermittent and low power outputs.

Solutions for autonomous or automatic cleaning have been developed for the aforemen- tioned problems. According to recent studies, autonomous cleaning solutions can pro- vide reliable cleaning performance while significantly reducing water consumption. The proposed robotic cleaning system is an economical, energy-efficient solution by combining automation, robotics, and renewable energy. This approach decreases maintenance requirements, improves energy generation, and allows various interna- tional initiatives to be taken on dependable and sustainable usage of solar energy.

Related Work

Solar power efficiency is hampered by the accumulation of dust and other particles present on the surface of the photovoltaic cells. Dust accumulation causes reduced transmission of solar lighting, which ultimately leads to losses in output power. A few authors have utilized different solar panel cleaning technologies to reduce such losses and maximize power generation. Presently available literature differentiates solar panel cleaning techniques based on their manual, semi-automatic, and fully automatic nature. Various studies revealed the negative impacts of dust accumulation on the efficiency of PV panels. Hussain et al. [9] observed the power loss impacts of dust generation through experimentation and concluded that there is great efficiency loss when the solar panels were not cleaned periodically. A comprehensive review introduced by research- ers in solar power literature, as invoked by [2], further reinforced the point that dust accumulation is one of the prime environmental considerations responsible for affect- ing the efficiency of solar power generation, primarily in arid and industrial zones. It also introduced the point that solar panels could achieve maximum efficiency through continuous cleaning, while regular manual cleaning through water is quite time-con- suming and unsustainable concerning water utilization, primarily when water is limited. In order to handle these issues, semi-automatic cleaning solutions have been deemed appropriate. Kumar & Patel in [8] introduced optimized cleaning solutions that can semi-automatize the cleaning solution in order to limit manual labour. In the same con- text, for example, Li & Zhao in [1] designed water-optimized solar panels cleaning robots that utilize regulated mechanisms to reduce water consumption during the clean- ing process. Even though these solutions can limit manual labour, they cannot fully utilize human capabilities due to the restricted functionality of the mechanical system. Fully automated robotic systems have received more attention due to their ability to potentially mitigate the aforementioned disadvantages. Comparative design work un- dertaken by [3] surveyed the design of various solar panel-cleaning robots and con- cluded that autonomy is possible to achieve and can assure uninterrupted quality and cost-effective operation. An automatically controlled solar panel-cleaning robot de- signed by [4] used motor-driven mechanisms to remove dirt from the solar panel with- out the assistance of humans. Nevertheless, the robot faced certain disadvantages such as navigation and edge detection and the angle of the solar panel. An automated dry- cleaning robot designed by [5], using microfiber cloths and removing the need to use water, solved the majority of the aforementioned disadvantages. There are also recent developments in incorporating smart technologies for the maintenance of solar panels. The IoT-based monitoring and control systems talked about in [6] allowed long-dis- tance monitoring, timing, and tracking of cleaning robots for solar panels, thus ensuring smart energy management. The review in [7] pointed out that while new-generation solar panel cleaning robots work well, issues like high production cost, lack of adapta- bility for different panel designs, and inefficient use of energy are still pending solu- tions.

On the basis of the review of the existing systems, it has been identified that, although considerable advancement has been achieved regarding the automation of solar panel cleaning, the current systems still have limitations regarding their cost, adaptability, and energy efficiency. Accordingly, the objective of this study would be to develop a compact, economically sound, and energy-efficient autonomous solar panel cleaning robot that would be equipped with enhanced sensors for safe cleaning as well as maxi- mum solar energy harnessing.

Methodology

System Architecture (Block Diagram)

Fig. 1 shows the block diagram of the automated solar panel cleaner. This system con- sists of a central controller Arduino UNO, DC motors for linear movement, rotating microfiber brushers for dry cleaning, IR sensors for edge detection, and a rechargeable battery. Input signals from sensors are processed through a microcontroller and then it sends the control signals to operate the motor for safe navigation and efficient cleaning of the solar panel.

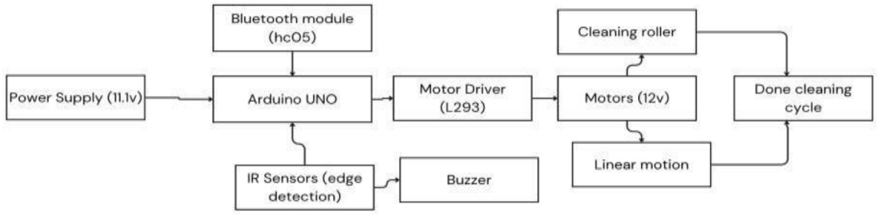

Fig. 1. *Block diagram of automated solar panel cleaning robot.*

Operational workflow (Flowchart)

Fig. 2: Operational workflow of the automated solar panel cleaning robot. This flowchart shows the sequence of actions by the robot from initializing movement to the end of a cleaning cycle. The program starts with checking the battery status followed by initializing the cleaning cycle. IR sensors are used continuously to detect edges and avoid accidental falls. Then, the rotating microfiber brushes are activated to perform the dry-cleaning cycle. After the cleaning is done, the robot moves back to the starting position, thereby completing one cleaning cycle.

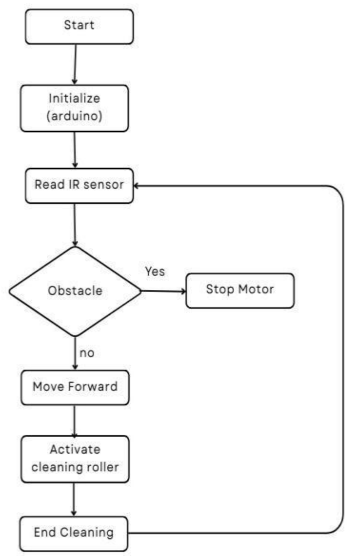

Fig. 2. *Flowchart of the automated solar panel cleaning robot operation.*

Components And Specifications

The The robot for automated cleaning of solar panels is designed using cost-effective and easily available hardware components to make it reliable and easy to maintain. Major components used in the robot are mentioned below.

The Arduino UNO microcontroller powers the robot and is in charge of the operation of the motors. The power supply consists of a 2200 mAh rechargeable battery; to ensure safe charging and discharging, and safety of the battery, a BMS is connected along with the battery.

The safe linear motion on the solar panel is because of the grippy rubber tires driven by a 12v DC motor. A microfiber brush roller driven by the 12v DC motor cleans off dust and debris deposited on the surface of the solar panel without damage during the clean- ing operation. This mechanism does not use water and reduces the complexity in maintenance.

Motor control is provided by using a L293D motor driver module, which allows bidi- rectional control of the DC motors. Bluetooth module enables the robot in communi- cating wirelessly with a smartphone application. IR sensors are integrated for edge- detection on inclined and elevated surfaces.

Result And Discussion

We tested the Automated solar panel cleaning robot on panels with varying levels of dust — light, moderate, and heavy — to evaluate its efficiency. A prototype equipped with DC motors, microfiber brushes, and edge-detection sensors was deployed for these experiments.

Experimental setup

A prototype robot equipped with two DC motors, rotating microfiber brushes, IR sensors, and a rechargeable battery was deployed on a solar panel. The robot was allowed to perform dry cleaning cycles while voltage and current readings were recorded before and after cleaning operations.

Observations And Data

Table 1. *Performance Improvement after cleaning*

Dust Condition	Voltage Before Cleaning (V)	Voltage After Cleaning (V)	Power Improvement (%)
Light Dust	17.2	18	4.7%
Moderate Dust	16.5	18.2	10.3%
Heavy Dust	15.8	18.4	16.5%

The performance improvement observed after the cleaning process is summarized in Table 1.

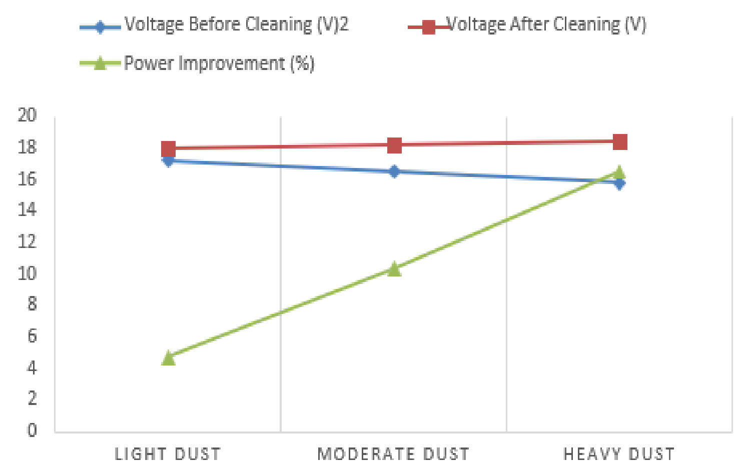

Fig. 3. *Power improvement after cleaning under different dust conditions.*

For better visualization, Fig. 3 depicts the graphical representation of the percentage power improvement based on the different conditions of dust. From the graph, it can clearly be observed that this cleaning robot works more efficiently with increased dust gathered on the panels. The maximum power recovered in heavily dusted panels was about 16.5%. It clearly indicates the critical need for regular and efficient cleaning in dusty environments.

Performance Analysis

The dry brush mechanism worked very well in removing fine dust without causing any damage to the surface.

- IR sensors provided correct edge detection to avoid accidents.
- Energy consumed by the cleaning operation was extremely negligible com- pared to the gain in restored output power.
- This reduced the water requirement by approximately 80% compared with conventional manual wet cleaning.

Limitations

- Right now, the prototype works well for small- to medium-sized panels.
- For larger solar farms, several robots or autonomous scheduling would be needed.
- Future improvements in traction and AI-based navigation could further im- prove coverage and performance.

The current system does not support complete mobile or web-based application integration for remote monitoring and control, thereby limiting real-time performance tracking and user accessibility.

Conclusion

This study presents an autonomous solar panel cleaning robot designed to improve photovoltaic efficiency in dusty environments. The system effectively removes dust using microfiber rotating brushes and ensures safe operation through IR-based edge detection. Experimental results demonstrate a significant improvement in power output, especially under heavy dust conditions, with up to 16.5% gain. The proposed solution reduces water usage, lowers maintenance cost, and minimizes human intervention compared to conventional cleaning methods. Although currently limited to small and medium-scale installations, the system shows strong potential for scalability. Future enhancements may include AI-based navigation and IoT-enabled remote monitoring for large solar farms.

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