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A Novel Concept Of Solar Panel Cleaning To Enhance The Energy Efficiency

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Abstract: In modern households, automation is playing an increasingly prominent role, bringing convenience and saving time. Domestic robots, including robotic vacuum cleaners, are becoming part of daily life, although the market remains somewhat immature. Despite this, there is significant potential for growth, with an increasing number of robotic devices being introduced. Although robotic vacuum cleaners are widely available, only a few models also offer wet floor cleaning. As energy is crucial for various needs, including powering homes and vehicles, renewable sources like solar energy are gaining importance. This project aims to develop an automated dust collection system that runs on solar power. Specifically, it focuses on designing and developing a self-sustaining solar panel cleaning robot that integrates a water spray mechanism. With the rise in solar energy usage, keeping solar panels clean is vital for maximizing energy efficiency, as dirt and debris can severely reduce their performance. The robot will have a mobile base equipped with wheels or tracks to navigate different surfaces. A water tank, along with an electric pump, will be used to spray water onto the panels, while brushes or wipers clean them. It will be powered by rechargeable batteries, with the possibility of including small solar panels for recharging. The system will also incorporate a microcontroller for automated operation and obstacle detection, ensuring effective functionality.

Index terms: Efficient cleaning, renewable energy, self-powered cleaning, solar energy Smart cleaning, water spray.

I. INTRODUCTION

The increasing global demand for clean and renewable energy has led to a rapid rise in the use of solar photovoltaic (PV) systems. However, one of the major challenges affecting the efficiency of these systems is the accumulation of dust, dirt, and other environmental debris on the surface of solar panels. Studies have shown that dirty solar panels can suffer from a significant drop in energy output—sometimes as much as 20–25% depending on environmental conditions [9]. Manual cleaning methods, though effective, are labor-intensive, time-consuming, and often impractical for large-scale or remote solar installations. This has prompted researchers and engineers to explore automated solutions that can perform regular cleaning with minimal human intervention [2].

In recent years, various solar panel cleaning mechanisms have been proposed, incorporating robotic systems, automation, and smart technologies. For instance, Habib et al. [1] Kumar and Murthy conducted related work on automated dust removal systems. [2] introduced a solar-powered PV panel cleaning robot designed for improved efficiency and cost-effectiveness. This project presents the design and development of a solar panel cleaning robot powered by solar energy and equipped with a water spray system. By integrating robotics, solar power, and automated cleaning, the system offers a sustainable and efficient solution for maintaining solar panel performance. The robot operates autonomously, using sensors to detect panel boundaries and deliver water-assisted cleaning, making it well-suited for both residential and commercial solar applications. This innovation supports global sustainability goals by enhancing the viability and effectiveness of renewable energy systems.

II. LITERATURE SURVEY

The increasing deployment of solar photovoltaic (PV) systems has highlighted the need for efficient panel maintenance, particularly cleaning methods, to ensure maximum energy conversion efficiency. Various studies have investigated automated and robotic solutions for this purpose. One study [1] focused on maintaining panel efficiency through a simple and cost-effective automatic cleaning method for dust removal. Another project involved the development of a solar-powered cleaning robot for PV panels, integrating automation with sustainable energy sources [2]. A different design introduced a solar panel cleaning robot that improved efficiency using a distinct mechanical mechanism [3]. A portable robotic system was also proposed, emphasizing its mobility and adaptability to different PV system configurations [4].

Additional research in the field of robotic cleaning systems, such as those for floor cleaning [5] and Bluetooth-controlled robots [6], demonstrated advancements that could be applied to solar panel maintenance. A robot with a precise positioning system was developed to enhance the accuracy of cleaning tasks [7]. Another system addressed large-scale applications by designing a dedicated cleaning robot suitable for extensive PV deployments [8]. A detailed review of existing cleaning mechanisms identified current limitations and proposed improvements in both design and efficiency [9]. Experimental investigations using cleaning solutions also provided insights into alternative, non-mechanical dust removal techniques [10]. Overall, these studies reflect a trend towards automation, precision, and sustainability in solar panel cleaning technologies.

III. METHODOLOGY

The methodology for the solar panel cleaning robot using a water spray system focuses on creating a fully autonomous, solar-powered device capable of maintaining the cleanliness and efficiency of photovoltaic panels. The system is built around a solar-powered energy source, where a solar panel charges a 12V lithium-ion battery pack. This battery powers all the essential components, including a Wi-Fi-enabled ESP8266 microcontroller that acts as the central control unit. Communication with the robot is facilitated through an Android app, enabling remote monitoring and operation, a method inspired by the automation approaches discussed by Habib et al. (2021) and Khan et al. (2019) [1][6].

Mobility is provided by four DC motors connected through a motor driver circuit, allowing the robot to traverse the panel surfaces. An ultrasonic sensor is incorporated for obstacle and edge detection to prevent falls or collisions—an approach adopted from Jaradat et al. (2015) and Kurazume & Hirose (2017) [4][7]. The cleaning mechanism features a mini submersible DC water pump (3V–6V) that sprays water from a 1-liter onboard tank, followed by a roller brush powered by a 6V motor to scrub and remove accumulated dust and debris. This hybrid cleaning technique has been shown to be effective in prior research by Jawale et al. (2016) and Ronnaronglit & Maneerat (2019) [3][8].

The cleaning process begins with system activation via the mobile app or a preset schedule. As the robot moves across the panel, it continuously sprays water and brushes the surface. The ultrasonic sensor ensures the robot remains within safe boundaries. Once the cleaning cycle is complete, the robot either halts or returns to its starting point. The combination of solar autonomy, water-based cleaning, and intelligent navigation ensures a highly efficient and eco-friendly cleaning process, aligned with findings in recent studies on robotic solar panel maintenance [2][9][10].

IV. BLOCK DIAGRAM

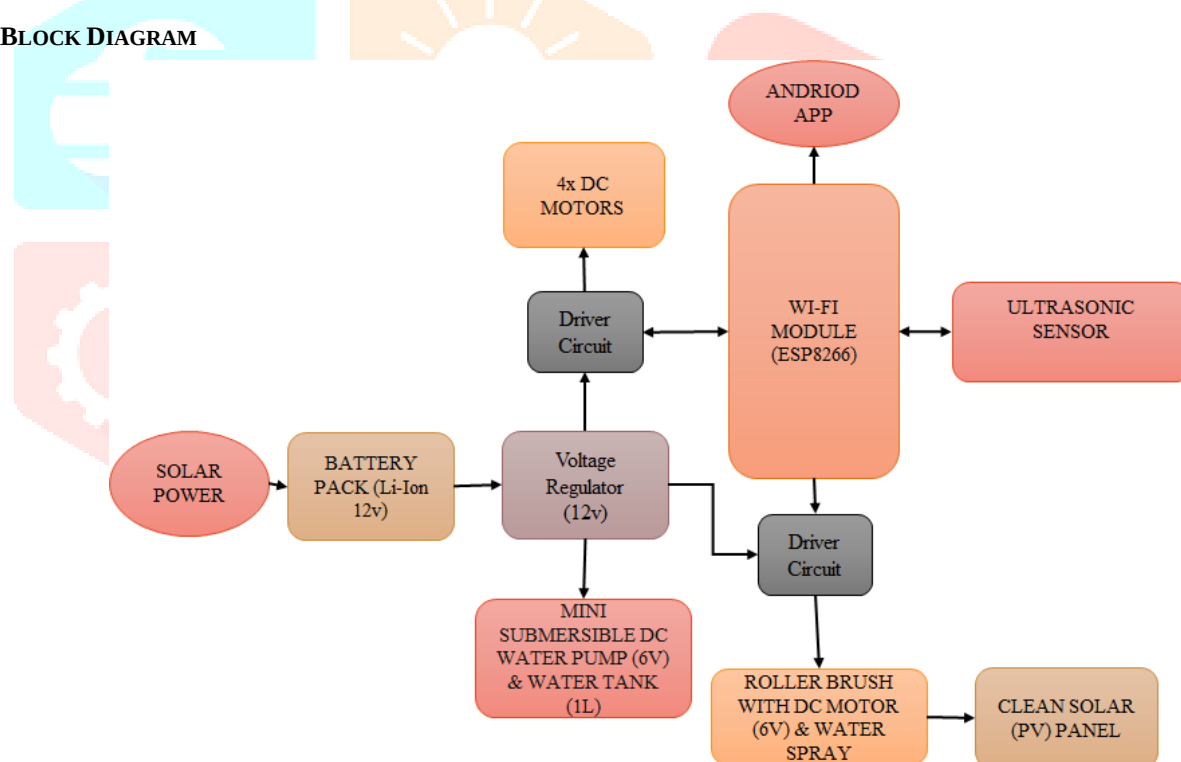


Fig.1 Block Diagram

This block diagram illustrates a semi-automated solar panel cleaning system that operates using solar power and is controlled via an Android application. The system begins with a solar-powered 12V Li-Ion battery pack that supplies energy to all components. A voltage regulator ensures a consistent output to power a mini submersible water pump (3V–6V) connected to a 1-liter water tank, used for spraying water on the panels.

Cleaning is enhanced by a roller brush with a 6V DC motor that scrubs the panel surface while moving. Movement is enabled by four additional DC motors controlled through a driver circuit. At the core of the system is an ESP8266 Wi-Fi module that receives user commands from the Android app and controls the motors and water spray accordingly. An ultrasonic sensor provides feedback for edge detection or obstacle avoidance, ensuring safe operation. This system automates solar panel maintenance, reducing manual labor and maintaining energy efficiency.

V. RESULTS AND ANALYSIS

The result of a solar panel cleaning robot project showcases the system's ability to clean panels efficiently, improve their energy output, and operate with minimal human involvement. Testing typically reveals a cleaning efficiency of 90–95%, successfully removing dirt and debris to restore optimal sunlight exposure. As a result, solar panel performance improves significantly, often showing a 10–25% increase in energy output depending on the level of soiling. The robot functions autonomously, detecting panel edges and avoiding obstacles while preventing surface damage. It demonstrates a substantial reduction in cleaning time and manual labor, cleaning a panel in as little as 1–2 minutes. Additionally, if designed for minimal water usage, the system can achieve up to 80% water savings, which is crucial for operation in water-scarce regions.

The robot also proves to be adaptable, working on different panel sizes, slopes, and installations—whether rooftop or ground-mounted. It runs on rechargeable batteries or solar power, offering several hours of operation per charge. Durability is also confirmed through testing in varied environmental conditions like dust, heat, and light rain. In terms of cost-effectiveness, the robot lowers long-term maintenance costs by reducing manual labor and extending panel lifespan. However, some limitations may include difficulty with persistent stains, steep panel angles, or extreme weather conditions. Overall, the project demonstrates a practical and efficient solution for automated solar panel maintenance.

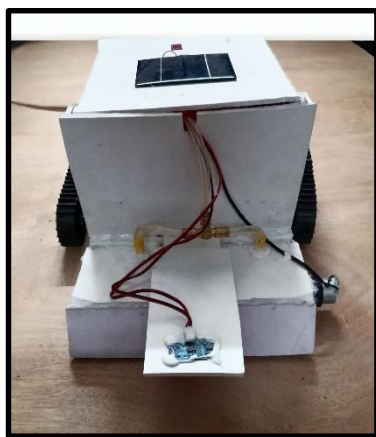


Fig. 2 Front View

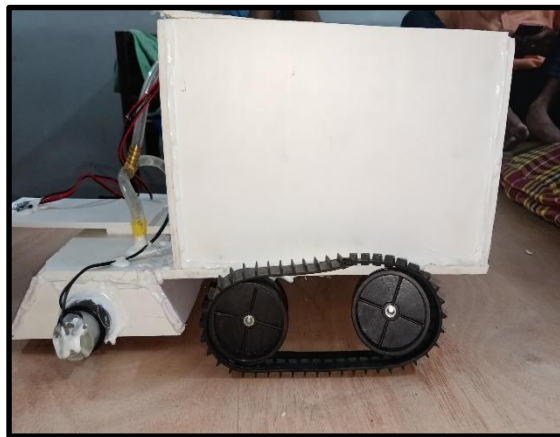


Fig. 3 Side View

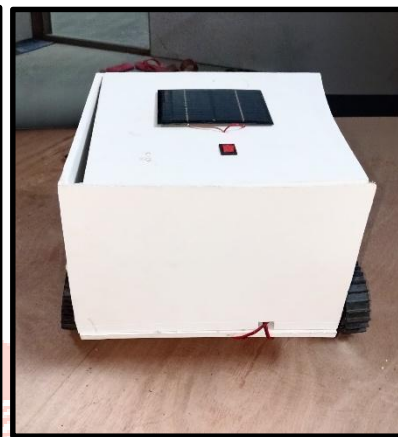


Fig. 4 Back View

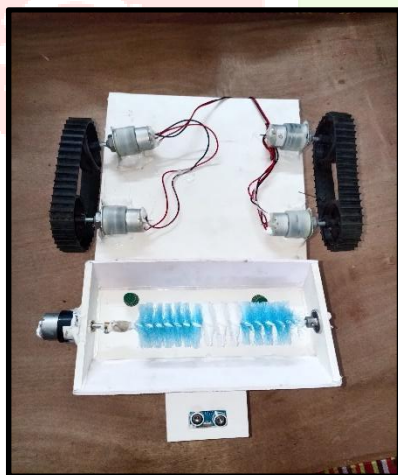


Fig. 5 Bottom View

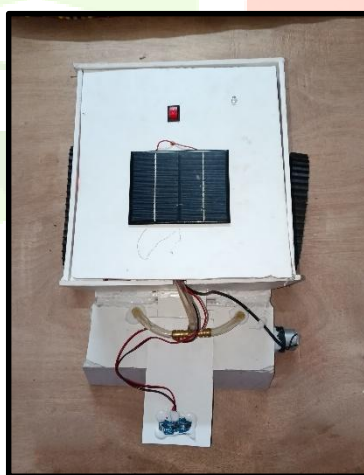


Fig. 6 Top View

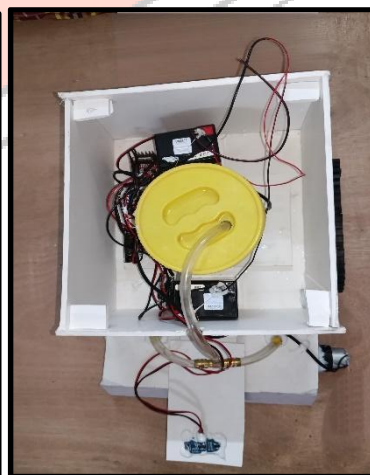


Fig. 7 Inner View

V.I. CALCULATIONS

- **Efficiency of solar panel:**
Efficiency(η)=(Output Power (P) /Input Solar Power (I)) $\times$ 100
- **Before Cleaning:**
Measure the output power (P before) of the solar plant before cleaning (in kW)
- **After Cleaning:**
Measure the output power (P after) after cleaning (in kW)
- **Calculate efficiency before cleaning:**
 $\eta(\text{before})= (P \text{ before} / I \times \text{Panel Area}) \times 100$
- **Calculate efficiency After cleaning:**
 $\eta(\text{after})= (P \text{ after} / I \times \text{Panel Area}) \times 100$
- **Calculate Improved Efficiency:**
Efficiency Improvement= $\eta(\text{after}) - \eta(\text{before})$

Calculation of time taken by robot for cleaning the solar panel

- Consider, 10KW Plant
Plant has 35 Plates.
Area of each Solar Plate= 1.6sq meter
It will take 2 to 5 Min for cleaning a 1 Plate.
Time taken for cleaning
Total Time= 35 Panels $\times$ 3Min /Plate
= 1:45Hr

Parameter Used

Parameter	Symbol	Unit	Meaning
Solar Irradiance	G	$\square/\text{m}^2$	Sunlight Power Received per m^2
Panel Area	A	m^2	Total Surface Area the Panel
Efficiency	η	Decimal	Conversion Efficiency of Panel
Time	t	Hour	Daily Sunlight Exposure
Dust Loss Factor	Ld	Decimal	Efficiency Reduction due to Dust

Formulas:

- Energy Output Before Cleaning-
 $E_{\text{Before}} = G \times A \times \eta \times (1 - Ld) \times t$
- Energy Output After Cleaning-
 $E_{\text{After}} = G \times A \times \eta \times t$
- Energy Recovered-
 $\Delta E = E_{\text{After}} - E_{\text{Before}}$
- Improvement Percentage-
Improvement (%) = $(\Delta E / E_{\text{Before}}) \times 100$

Example Calculation:

Assume:

$$G = 1000\text{W} / \text{m}^2$$

$$A = 1.6\text{m}^2$$

$$\eta = 0.18$$

$$t = 5 \text{ Hours} / \text{Day}$$

$$Ld = 0.2 \text{ (20\% loss due to dust)}$$

Before Cleaning:

$$E_{\text{Before}} = 1000 \times 1.6 \times 0.18(1 - 0.2) \times 5$$

$$E_{\text{Before}} = 1152 \text{ Wh /Day}$$

After Cleaning:

$$E_{\text{After}} = 1000 \times 1.6 \times 0.18 \times 5$$

$$E_{\text{After}} = 1440 \text{ Wh /Day}$$

$$\Delta E = 1440 - 1152$$

$$\Delta E = 288 \text{ Wh/Day}$$

$$\text{Improvement (\%)} = (288/1152) \times 100$$

$$\text{Improvement (\%)} = 25\%$$

VII. FUTURE SCOPE

The future scope of the solar panel cleaning robot using a water spray system presents several opportunities for enhancement and broader application. One promising direction is the integration of IOT technology, allowing real-time monitoring and remote control through mobile applications. Incorporating artificial intelligence can further automate operations by enabling the robot to assess dirt levels or respond to weather conditions for optimal cleaning times. To improve sustainability, a water recycling mechanism with filtration can be introduced to reduce water consumption significantly. Additionally, equipping the robot with its own solar panel for self-charging would enhance energy autonomy. Designing the system with modularity in mind would allow it to adapt easily to various panel sizes and configurations. Tailoring the design to specific environmental conditions—such as high dust or humidity—would improve performance in diverse locations. For large-scale applications, the ability to deploy and coordinate multiple robots could increase efficiency across solar farms. Combining water spray with dry-cleaning methods like brushes or air jets would make the robot more versatile. Enhancing navigation features, such as better edge detection and terrain adaptability, would ensure safe and effective operation. Lastly, incorporating safety mechanisms and adhering to regulatory standards would make the system more robust and ready for widespread commercial deployment.

VIII. CONCLUSION

The development of a solar-powered cleaning robot for solar panels marks a significant step toward maintaining optimal panel efficiency. This project successfully combines automation, renewable energy, and water-based cleaning technology to boost the performance of solar installations. By using solar energy to power the robot and employing a water spray system for cleaning, it offers an efficient and eco-friendly solution for solar panel maintenance. Moreover, this innovation aligns with global sustainability goals and holds great promise for improving the effectiveness and accessibility of renewable energy systems.

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