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Original Article

Design of Automatic Solar Panel Cleaning Robot System for Industrial Applications

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Abstract - *The main sources of solar power generation in solar farms or systems are arrays of photovoltaic panels. Even on a single solar panel in an array, dust and debris buildup can reduce PV panel efficiency, despite the fact that solar energy is preferred in sun-rich areas because it is clean. Global interest in more energy-efficient and sustainable energy production has resulted from this. Solar panels are becoming the main electrical power source for many industrial applications. The surface of the panels should be clear of dust and other particles that obstruct photon passage so that the PV cells can function at maximum efficiency without any energy loss. As a result, PV panels must be cleaned regularly. Current manual cleaning techniques require considerable time and energy, with a notable absence of automated solutions. Along with this, water is commonly employed in the cleaning processes, often resulting in wastage due to inefficient usage. However, such cleaning methods are impractical in areas experiencing water scarcity, where conservation and efficient utilization of water resources are paramount. Hence, the Automatic Solar Panel Cleaning Robot is proposed to address this issue. An Arduino controlling system regulates the robot's movements while it is cleaning. To efficiently clear soil and dirt from the PV panel surfaces, it comes with a microfiber brush. Introducing an IoT-based automation system significantly reduces the necessity for manual intervention, hence lowering operational costs. Moreover, the system offers remote monitoring and management of cleaning operations through IoT-enabled devices like smartphones, tablets, or through web platforms.*

Keywords - *Solar panels, Arduino microcontroller, Sustainability, Energy efficiency, Solar panel cleaning system, Photovoltaic panels, Internet of Things, Renewable energy, Dry cleaning, IoT.*

1. Introduction

In today's world, energy-related issues are getting more critical. Global interest in more energy-efficient and sustainable energy production has resulted from this. Solar panels are becoming the main electrical power source for many industrial applications. The surface of the solar panels must be clear of dust, debris, and other particles that obstruct photon passage in order for them to function as efficiently as possible without losing energy.

Dust can reduce a PV panel's efficiency by as much as 25% to 30%, depending on the environmental conditions. To address these challenges, developing a systematic and efficient robotic device for large-scale panel cleaning with minimal or no water usage is essential. The projected project goals are to provide a systematic and efficient answer for solar panel cleaning while minimizing water usage. It is designed to navigate on the solar panels and removes dust and debris with precision and consistency. Integrating ultrasonic sensors ensures precise navigation and detection of solar panel edges, which provides optimized cleaning coverage.

Additionally, integrating IoT technology provides real-time remote monitoring and control capabilities, allowing the users to monitor and control the process using IoT devices such as smartphones, tablets or web interfaces over the internet. This facilitates convenient monitoring and management of the cleaning system from any location, hence enhancing operational flexibility and efficiency. By automating the cleaning process, the robot reduces the intervention for manual labor and also minimizes the risk of injury associated with manual cleaning methods. It also represents a significant step towards achieving sustainable and efficient solar energy production on a large scale.

In this area, there are many problems faced in day-to-day life, like dust on panels, panels efficiency, weather, etc. So, to overcome these problems, it's very important to keep all the solar panels clean. So, to utilize most of the benefits of using solar panels, a more efficient system to clean the panels is important.

2. Literature Review

B. Sutam et al. [1] settled a solar panel cleaning robot controlled by IoT technology. The study aims to optimize the movement system and maintenance of solar panels. Differential kinematics principles are applied to calculate the robot's motion and navigation.

The microcontroller is integrated with IoT technology for remote management. Through simulations, the effectiveness of the robot in cleaning a 100cm x 165cm path within 110 seconds is demonstrated, and the result shows that the robot's movement speed is quite good. Y. Zong et al. [2] proposed a novel dust removal cleaning robot for rooftop photovoltaic panels, eliminating the need for water. The migration of dust particles inside a sealed enclosure was investigated using computer simulations utilizing the Dense Discrete Phase Model (DDPM). Dust removal under various situations, such as exit directions, brush rotating rates, and directions, was examined using the L16 Taguchi experimental method.

L. A photovoltaic autonomous cleaning robot with sophisticated characteristics like a current blocking mechanism was created by Sun et al. [3]. Experiments demonstrate that the robot can operate over a range of 90-degree elevation angles and effectively boost solar panel power. This innovation also addresses the shortcomings of water-intensive solutions like water wheel washing and manual cleaning methods.

R. J. Rupin et al. [4] developed a method that uses temperature sensors to detect dust, dirt, and debris accumulation on solar panels in an effort to improve energy generation efficiency. It uses gear motors and an MLX90614 sensor to facilitate dirt removal. The MLX90614 sensor uses infrared radiation to measure panel temperature. The gadget improves existing methods with a motor-driven dirt removal strategy by comparing panel temperature to ambient temperature for dirt detection.

According to a different study put out by A. Badhoutiya [5], there is a four-step cleaning procedure that eliminates the need for liquids. The glass panels are first cleaned with compressed air and then wiped with a moving roller. Servo motors provide the motion along the length of the panel, and this arrangement is electrically controlled. Once every twenty-four hours, the proposed model focuses on cleaning a single panel.

V. S. G et al. [6] suggested employing an automated brush-based system enhanced by IoT technology to address this issue. A microcontroller and an Android smartphone work together to regulate the system and give users real-time updates on how it's doing. The portability of this technology allows for its deployment in various locations, offering convenience and accessibility to users.

N. Prastomo et al. [7] developed an automatic solar panel cleaner that moves along the solar panel frame to clean the panel rows efficiently. Tests were conducted using incense ash to simulate dust accumulation on a 100 Wp solar panel. Different cleaning methods, including using shrink, a wiper only, a sprinkler only, and running water, were analyzed.

The results showed that combining a wiper with a sprinkler was the most effective method, achieving a cleaning efficiency of 97.9%. Additionally, the study also claimed that successful cleaning led to a significant increase in power output under specific irradiance conditions.

Overall, it is clear from existing research that regular cleaning and monitoring of solar panels plays a crucial role in sustaining their efficiency and extending their service life. However, some of the literature review reveals several limitations. These include dependency on specific environmental conditions, cost of implementation, maintenance requirements, energy consumption, etc.

This paper addresses the aforementioned limitations identified in existing research regarding solar panel maintenance. The paper describes the workings of the Automatic Solar Panel Cleaning Robot, organized as follows: Section 3 describes the components used to design the prototype. The methodology adopted for cleaning solar panels is outlined in Section 4. Section 5 delves into the experimental results, concluding with Section 6. All the above-referred papers show efficient results in their experimentations.

3. Components Used

3.1. Arduino Mega 2560

This is a microcontroller panel based on the ATmega2560 chip. With its ample number of pins and memory capacity, the Arduino Mega can effectively manage the sensors, motors, and other peripherals required for the robot's operation. It serves as the central control unit for the solar panel cleaning robot, enabling precise and reliable operation.

3.2. Li-ion Battery

The battery serves as a crucial power source that offers a relatively high energy density, making it suitable for powering the robot's operations efficiently. The battery can provide extended operating times for the robot between charging cycles. By connecting three 3.7V batteries, each of 3800 mAH in series, the project operates on a total of 12V, providing sufficient power to drive the robot's various components efficiently and effectively.

3.3. Motor Drivers

60 RPM DC motors power the robot's wheels, and their movement is controlled by the L298N motor driver, which communicates with the Arduino Mega 2560. This motor driver module can control two DC motors separately thanks to its dual H-bridge circuits.

Each H-bridge can use PWM signals to regulate a motor's speed and drive it either forward or backward. The L293D motor driver controls the cleaning brush connected to a motor. The microcontroller activates the motor by sending appropriate signals to the motor driver and operates the cleaning brush.

3.4. DC Motors

A 60 RPM DC motor is used to power the cleaning brush mechanism. Additionally, four motors with the same specifications are utilized to drive the wheels of the robot chassis. These motors ensure the effective operation of the cleaning robot, facilitating both the washing procedure and the robot's mobility on the panel surface.

3.5. Ultrasonic Sensors (HC-SR04)

In this project, four ultrasonic sensors are used – front, back, left, and right sides of the robot chassis. These sensors produce high-frequency sound waves and track how long it takes for them to return after coming into touch with an item. Because of this time delay, the robot can recognize the edges of the solar panels and take the proper action, which allows the sensor to calculate the object's distance.

3.6. ESP8266 Node MCU Board

The function of the ESP8266 Node MCU board is battery monitoring. It remotely monitors the health of the robot's battery by measuring the voltage. Furthermore, a voltage divider circuit is constructed, safely reducing the battery voltage to a level suitable for the Node MCU's analogue input pin.

The estimated battery level information is then wirelessly transmitted over Wi-Fi to a designated server or mobile application for remote monitoring. By monitoring the condition of the batteries, the robot's performance can be optimized, and battery replacements may be planned ahead of time to avoid downtime during cleaning cycles.

4. Working and Methodology

This paper proposes the design of a user-friendly solar panel scrubbing robot that can move around and clean solar panels. The robot uses a microcontroller-based control system for autonomous operation and ultrasonic sensors for edge detection to guarantee complete cleaning coverage.

4.1. Robot Design and Control System

To move the robot, four 60 RPM DC motors are installed on a chassis with four wheels. The Arduino Mega 2560 microcontroller board interfaces with the L298N motor driver module.

It receives signals to regulate the speed and direction of the wheels. This allows for precise robot movement during cleaning operations.

The robot is powered by a 12V lithium-ion battery pack. This pack is constructed by connecting three individual 3.7V 3800mAh batteries in series, providing sufficient power for extended cleaning cycles.

Four ultrasonic sensors are strategically positioned at the front, back, left, and right sides of the robot's chassis for the primary obstacle detection mechanism. This sensor continuously scans the environment and detects the edges of the solar panels. The speed of the motors must be as high as possible with a sufficient and efficient solar panel cleaning mechanism system. Hence, the motors are chosen in such a way that all motors provide good speed to their mechanism.

4.2. Working

The following diagram represents the flowchart and working methodology of the Automatic Solar Panel Cleaning Robot.

Upon activation, the robot commences a forward motion, initiating the cleaning process simultaneously. When an ultrasonic sensor detects an approaching edge, the robot halts for 5 seconds to prevent accidental falls.

It then turns left to clean a new section of the panel. This process of forward movement, edge detection, stopping, turning, and resuming cleaning is repeated until the entire solar panel surface is traversed.

Along with the cleaning operation, a separate battery monitoring system using IoT is implemented to monitor the battery health of the robot remotely. This system ensures the battery's optimal performance and, hence, prevents unexpected shutdowns.

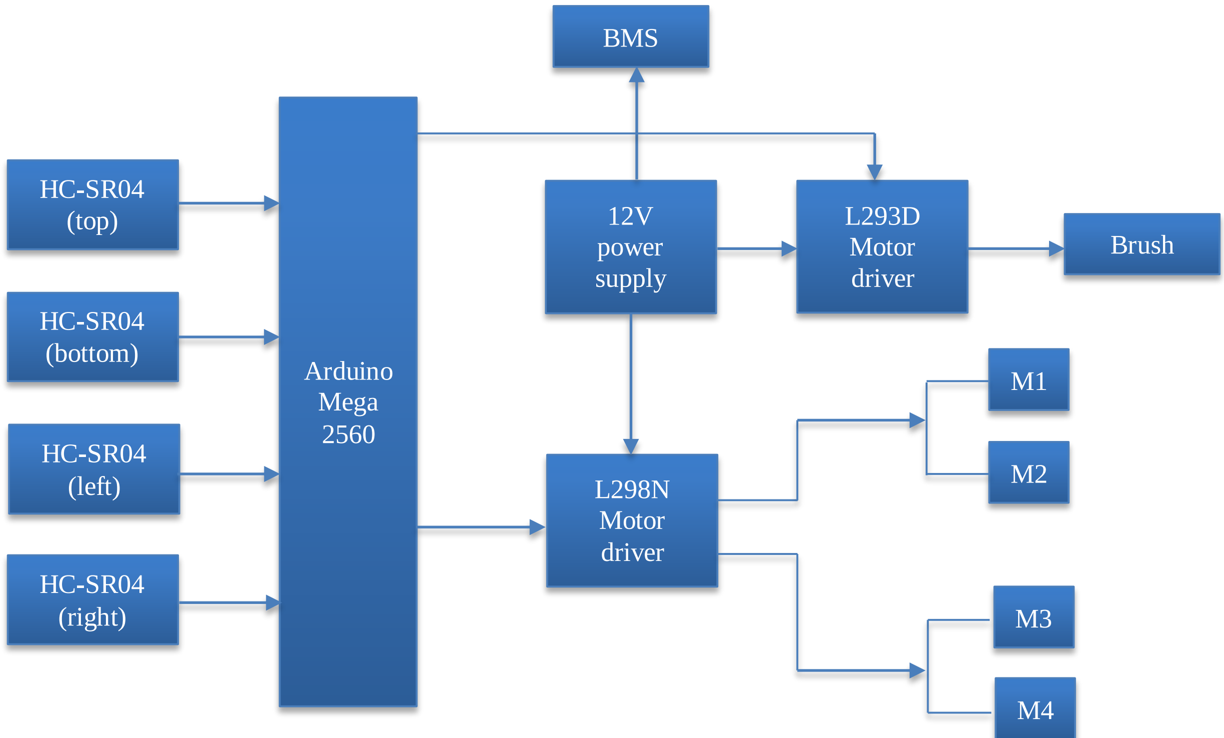

Fig. 1 Block diagram of the solar panel cleaning robot

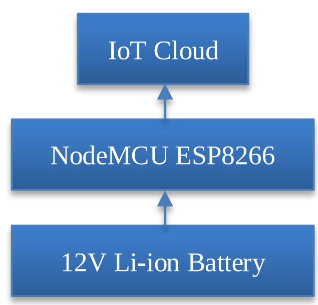

Fig. 2 Battery monitoring system using IoT

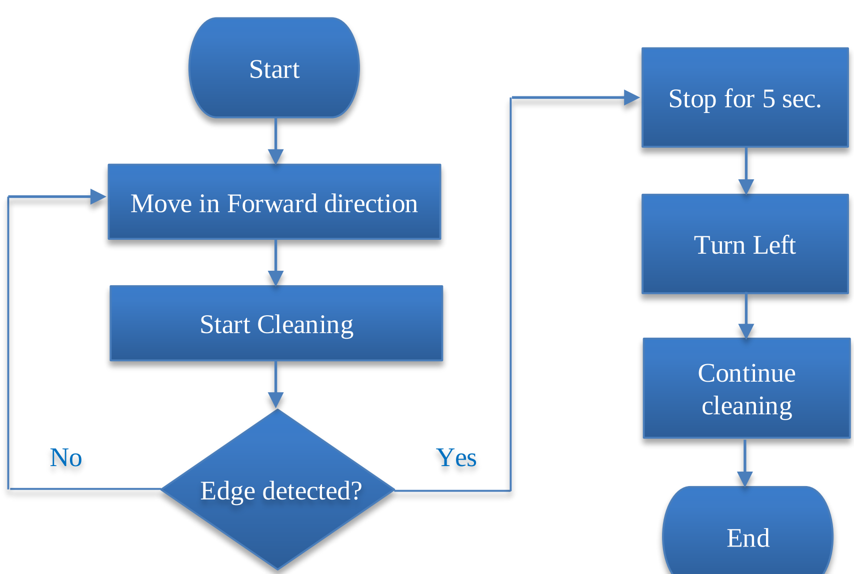

Fig. 3 Flow chart of automatic solar panel cleaning robot

The ESP8266 Node MCU module serves as the brain of this monitoring system. It utilizes a voltage divider circuit to safely measure the battery voltage. This measured voltage is then converted into an estimated battery level. Here, we are saving the water which is used for cleaning purposes by using more dimension brush to save the water. Only that amount of water gets utilized to clean the panels once the water reaches the brush section, and in this way, we can save the water.

The NodeMCU module transmits this estimated battery level data wirelessly via Wi-Fi to a designated server or mobile application. This allows for remote monitoring of the battery's health at any time. Users can now plan battery replacements, avoiding downtime during cleaning cycles.

4.2.1. Circuit Diagram

Figure 1 represents the circuit figure of the proposed Instinctive Solar Panel Scrubbing Robot. Proteus Simulation Software develops this. Four 60 RPM DC motors are connected to the Arduino Mega through the L298N motor driver.

A DC motor is connected to a cleaning brush and is controlled by an L293D motor driver. Four ultrasonic sensors are connected to the robot chassis's top, bottom, left, and right sides for edge detection and are controlled by an Arduino Mega microcontroller. A NodeMCU board is connected to a 12V battery along a voltage divider circuit for the battery monitoring system. The voltage divider circuit is designed using two resistors of 26.1k ohms and 10k ohms.

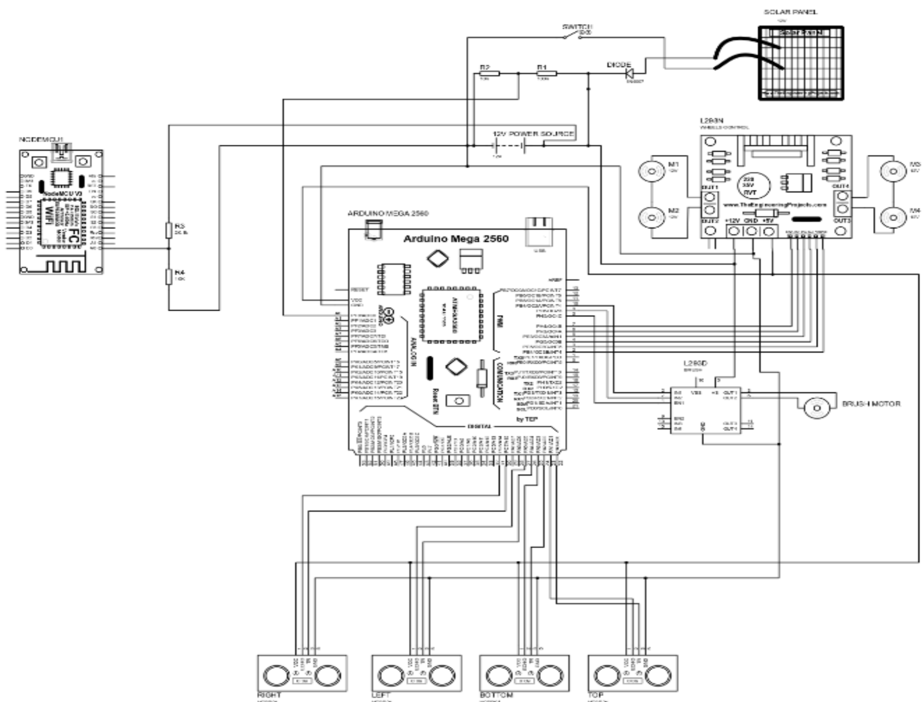

Fig. 4 Circuit diagram of the automatic solar panel cleaning robot

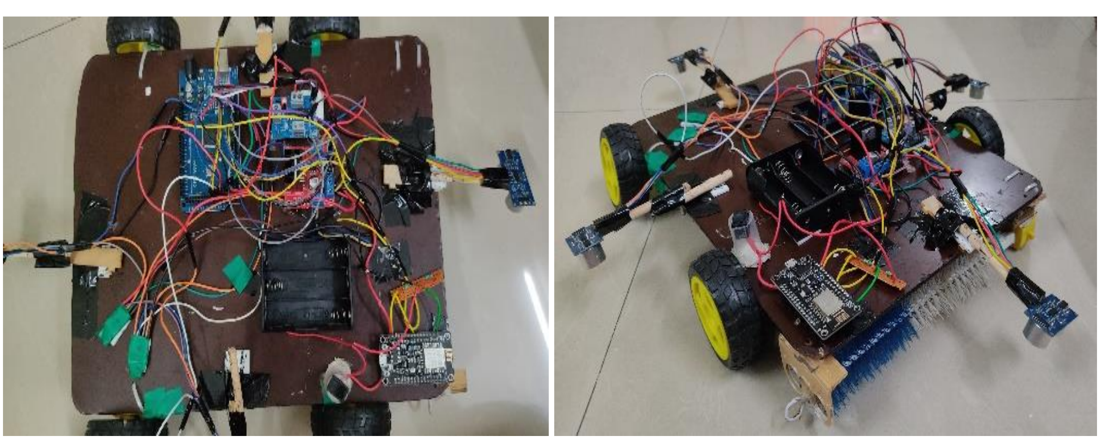

Fig. 5 Hardware implementation of automatic solar panel cleaning robot

5. Results

The evaluation of the efficiency of the proposed project was conducted to assess its effectiveness. Measurements of peak values of electric parameters such as Voltage, Current, and Power from the PV solar panels were recorded over a three-day period, both before and after the cleaning process.

A multimeter was used as the measuring instrument to measure the peak values of current and voltage by using variable resistance. The collected data is presented in Tables 1 and 2, which illustrate the belongings of dust, debris, etc., on the performance of the PV modules.

Examining the tabulated data reveals a clear correlation between dust accumulation and reduced system output. The pre-cleaning measurements displayed a significant decrease in performance compared to the post-cleaning measurements. This observation confirms that dust and other contaminants significantly reduce the efficiency of PV modules, which hinders their power generation capabilities.

Figure 6 provides a visual representation of the impact of cleaning the solar panels by the robot over three days. It is evident from the figure that the power output (W) exhibits an upward trend after each cleaning session, boosting the efficiency and overall performance of the solar panels. When we compare our results with other existing results, we find that after cleaning, our panel works more efficiently than others.

A particularly noteworthy observation is the significant increase in power output observed on Day 3 after cleaning. The power output increased from an initial value of 48.198 W to 54.498 W.

This substantial improvement highlights the negative impact of accumulated dirt, dust, debris and other pollutants on the ability of PV panels to harness solar energy effectively. The cleaning process effectively addresses this issue, leading to a noticeable enhancement in power generation.

Table 1. Performance of solar panel before cleaning

No. of Days	Voltage (V)	Current (A)
Day 1	17.8	2.7
Day 2	17.9	2.82
Day 3	17.4	2.77

Table 2. Performance of solar panel after cleaning

No. of Days	Voltage (V)	Current (A)
Day 1	18.2	2.9
Day 2	18	2.86
Day 3	18.6	2.93

This solar cleaning robot system provides 20% more accuracy in cleaning the panels than existing systems. Also, it saves energy for its functioning.

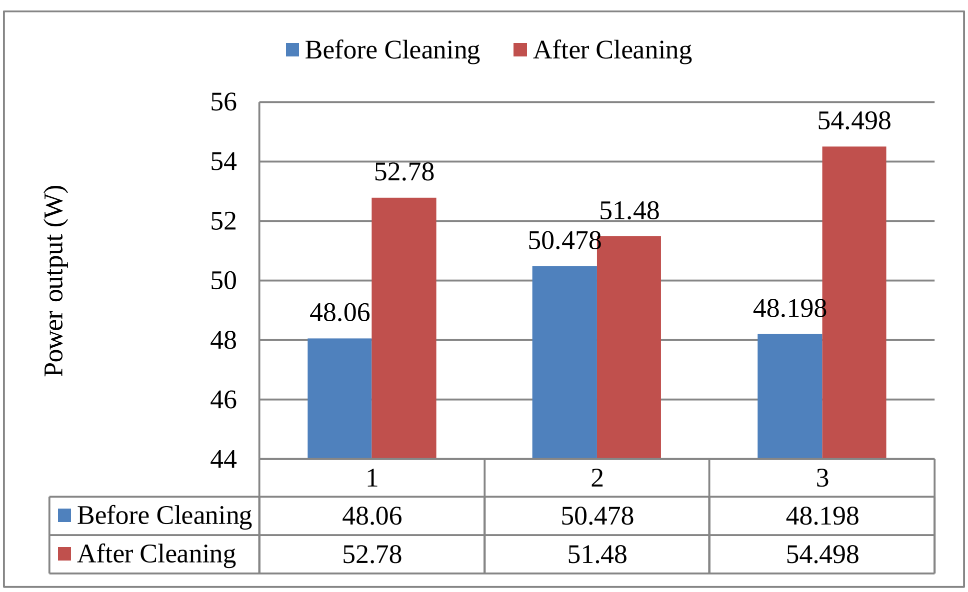

Fig. 6 Power generated by the solar panels before and after cleaning

6. Conclusion

The proposed project has successfully developed and tested an Automatic Solar Panel Cleaning Robot that leverages the power of the IoT technology. The robot utilizes ultrasonic sensors and an Arduino Mega controller for efficient panel cleaning. As a result, there is less need for manual intervention, which lowers labour costs and injury hazards. One major advantage of this robot is its ability to operate without water. It is a particularly desirable choice for arid and dry regions and locations with limited water supply because it avoids water waste. Traditional cleaning methods usually require water, which is scarce in arid areas. This robot, however, offers a practical alternative that ensures optimal solar panel efficiency without straining water supplies. This system can be used more effectively in industrial processes.

Additionally, IoT technology makes data collection and remote monitoring possible. The benefits of this integration go far beyond straightforward automation. Offering real-time battery health tracking enables preventive maintenance procedures.

In conclusion, this innovation provides a practical way to clean solar panels in an automated and sustainable way, paving the way for a more effective and environmentally responsible way to manage renewable energy infrastructure.

Future Scope

The potential of the Automatic Solar Panel Cleaning Robot has been successfully illustrated by the research endeavor. Simplifying the system over the next development phase can increase its adaptability for large-scale production. It is possible to combine proximity sensors and thermal camera modules to improve panel inspection and interactivity.

Combining Artificial Intelligence (AI) and machine learning techniques enhances the robot's intelligence and decision-making abilities. These algorithms can predict cleaning needs, optimize cleaning routes for efficiency, and even identify potential maintenance issues before they become issues by examining sensor data.

Furthermore, by utilizing state-of-the-art sensor technologies like LiDAR (Light Detection and Ranging), which can provide high-resolution 3D mapping, the robot would be able to navigate in challenging areas and clean panels more precisely.

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