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SMART SOLAR PANEL CLEANING SYSTEM

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Abstract: This study presents an innovative automated system for cleaning solar panels, aiming to improve energy efficiency and simplify maintenance. Solar panels often accumulate dust, dirt, and bird droppings due to their upward tilt, which reduces their ability to absorb sunlight and lowers power output. Traditional cleaning methods are often manual and inefficient. By integrating smart technology, the proposed system ensures regular and effective cleaning without human intervention. This not only boosts energy generation but also extends the operational lifespan of the panels. The approach represents a sustainable solution at the intersection of renewable energy and automation, optimizing solar energy system performance..

Keywords **– Automation , Renewable Energy , Smart Technology , Solar Efficiency , Dust Removal.**

I. INTRODUCTION

A solar array, comprising a series of panels, is employed to cater to higher connected loads. With a peak laboratory efficiency of 32% and an average efficiency ranging from 15% to 20%, maximizing energy recovery from solar power systems becomes imperative. In dusty environments, prevalent in regions like India, dust particles settling on solar panels impede the solar energy reaching the cells, resulting in a potential 15% reduction in power output if the modules go uncleaned for just a month.

The overarching objective of this project is to design and develop solar panel cleaning technology that significantly boosts efficiency and energy output. While some studies have linked reduced output to increased costs, particularly in commercial installations, our focus has been on a smaller scale, emphasizing residential use, rooftops or terraces to maximize sunlight exposure. Consequently, the task of cleaning these panels could entail homeowners climbing onto roofs, a potentially hazardous endeavor. Alternatively, hiring a professional cleaning service becomes an option, though it may come with additional costs. This innovative cleaning solution strives to alleviate these challenges, making solar energy more accessible and efficient for residential users.

II LITERATURE SURVEY :

S. No	Title	Technology Used	Methodology
1.	Automatic Cleaning of Solar Panel	Arduino based control system, Sensor integration.	Object Detection and Decision Making Conduct test in controlled environments to evaluate the system's performance under various conditions
2.	A Review on Solar Panel Cleaning Robot using IoT	IoT platform (Blynk app), Microcontroller, Motor drivers, Sensors.	Robotic Cleaning System with IoT Integration CloudBased Data Analysis and Optimization
3.	Solar Energy Monitoring System by IOT	Raspberry Pi, Flask Framework, Web- based monitoring dashboard.	System Integration and Testing
4.	IoT based photovoltaic monitoring system application	IoT based monitoring system, Real time data acquisition, Web and Bluetooth.	Develop software to acquire sensor data and process it to extract relevant information.

The system uses sensors to detect dirt and dust on the solar panels. The system is controlled by a microcontroller that processes sensor data and triggers the cleaning process. A mobile application is used to monitor the system's status and control its operation remotely. [1]
The research papers emphasize the critical role of solar panel cleaning in maximizing energy output and extending system lifespan. To address this, researchers propose innovative IoT-based robotic solutions. [2].
The research paper discusses an IoT-based solar energy monitoring system.The collected data is transmitted to a cloud platform via a wireless communication module. The system can also be remotely controlled and monitored through a user-friendly interface. [3]
The research paper focuses on developing an IoT-based system to monitor photovoltaic (PV) systems.[4].
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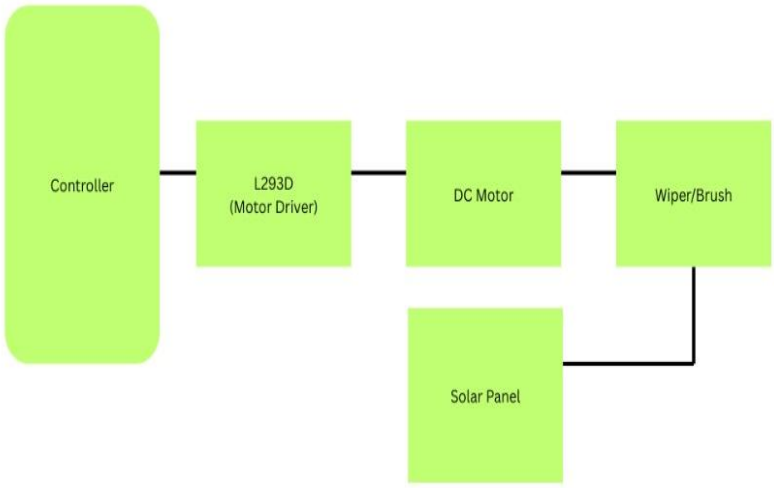
III SYSTEM ARCHITECTURE :



The proposed smart solar panel cleaner is designed to autonomously clean dust and debris from solar panels, thereby improving their efficiency and reducing the need for manual maintenance. The system is built on a mobile cleaning structure integrated with a motorized brush mechanism, controlled by an Arduino microcontroller.

The movement of the cleaning structure is achieved through DC motors connected to wheels that allow the system to traverse across the surface of the solar panels. A rotating brush, also driven by a DC motor, is mounted beneath the structure and positioned to make direct contact with the panel surface for effective cleaning. Both the driving motors and the brush motor are interfaced with the Arduino via an **L293D motor driver IC**, which facilitates bidirectional control of the motors using low-power digital signals from the Arduino.

The Arduino microcontroller is programmed to sequentially control the operation of the motors: it first activates the wheel motors to move the structure forward while simultaneously powering the brush motor to rotate. Once the structure has completed its cleaning path across the panel, the Arduino can reverse the wheel motors to bring the system back to its original position, ensuring the panel is cleaned in both directions.

III CONTROLLER CODE :

```
void setup() {
  // Set motor control pins as outputs
  Serial.begin(115200);
  pinMode(IN1, OUTPUT);
  pinMode(IN2, OUTPUT);
  pinMode(IN3, OUTPUT);
  pinMode(IN4, OUTPUT);
}

void loop() {
  // Rotate motors clockwise
  digitalWrite(IN1, HIGH);
  digitalWrite(IN2, LOW);
  digitalWrite(IN3, HIGH);
  digitalWrite(IN4, LOW);
  delay(50000); // Wait for 50 seconds

  // Rotate motors counterclockwise
  digitalWrite(IN1, LOW);
  digitalWrite(IN2, HIGH);
  digitalWrite(IN3, LOW);
  digitalWrite(IN4, HIGH);
  delay(50000); // Wait for 50 seconds
}
```

ArduinoUNO:

The Arduino is the main controller that runs the code. It continuously sends signals to the motor driver to control the direction of the motors. The logic written in the code decides when and how the motors will rotate.

Motor Driver (L293D):

The L293D motor driver receives control signals from the Arduino through four pins (IN1, IN2, IN3, IN4). It uses these signals to rotate two DC motors in either clockwise or counterclockwise direction.

Pin Configuration in Code:

- IN1 and IN2 control Motor A (used for back-and-forth motion).
- IN3 and IN4 control Motor B (used for brush rotation).

  These are defined at the beginning using #define to make the code cleaner.

Setup Function:

The setup() function runs once. It sets all the motor pins as outputs using pinMode(). It also starts serial communication, which is optional and can be used for debugging or monitoring.

Loop Function:
The loop() function runs continuously.

- First, it rotates both motors in the clockwise direction by setting IN1 and IN3 to HIGH and IN2 and IN4 to LOW.
- It keeps the motors running for 50 seconds using delay(50000);. During this time, the brush moves forward while rotating.
- Then, it reverses the direction of both motors by switching the HIGH and LOW signals. This makes the brush move backward while still rotating.
- Again, it waits for 50 seconds using the delay.This cycle repeats endlessly, keeping the brush moving back and forth across the solar panel.

IV RESULTS :

We successfully designed, developed, and tested an automated solar panel cleaning system to improve panel efficiency by removing dust and debris. The system uses an Arduino UNO to control a rotating brush that moves back and forth across the panel surface. Two DC motors—one for linear motion and one for brush rotation—are managed through an L293D motor driver.

During testing, the system effectively cleaned the panel within a 50-second forward and return cycle using time-based control. While this worked well in a controlled setup, future versions should include limit switches or sensors for real-time feedback and better precision.

The mechanical structure supported smooth movement with minimal friction. Motors handled the load well, but for larger setups, stronger and waterproof components are recommended. The system consumed low power and can be made self-sustaining by integrating solar charging.

In conclusion, the project provides a working prototype of a cost-effective, eco-friendly cleaning system, highlighting the practical use of embedded systems in renewable energy maintenance.

V CONCLUSION :

The Smart Solar Panel Cleaning System offers an automated, efficient way to keep solar panels clean, improving energy output and reducing maintenance needs. It conserves water, minimizes manual labor, and supports sustainable energy practices.

Challenges like sensor integration and cleaning mechanism optimization were tackled through iterative testing. Future upgrades could include machine learning for predictive cleaning and IoT for remote monitoring, making the system smarter and more efficient.

This project not only cuts costs and boosts panel performance but also supports eco-friendly energy solutions. Overall, it marks a strong step toward smarter, scalable, and sustainable solar maintenance**3.4Statistical tools and econometric models**

This section elaborates the proper statistical/econometric/financial models which are being used to forward the study from data towards inferences. The detail of methodology is given as follows.

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