# Robotic Solar Panel Cleaner

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**Abstract -** Solar energy is currently one of the most widely used sources of electricity generation. The deposition of dust (also known as soiling) on the surface of solar panels limits the amount of sunlight that reaches the solar cells beneath, decreasing the solar panel's efficiency. Cleaning solar panels is challenging due to dust and water stains, and manual methods are inefficient and time-consuming. As a result, this study describes the design of a robot for cleaning the surface of a PV solar panel. The design includes a DC motor for mobility, an Ultra-sonic sensor, and an Arduino controller system to control the robot while it cleans the panel surface. The cleaning part has a wiper on the front side of the robot and a smooth spongy brush on the back side. This combination of equipment can control the robot while also cleaning the panel's surface. The results demonstrate that the created robotic solar panel cleaner will be able to clean the photovoltaic solar panel effectively without damaging the panel's surface, thus enhancing the solar panel's performance sustainably and affordably.

***Key Words***: Photovoltaic Solar panel, Cleaning Robot, Arduino Controller System, Ultra-sonic sensor.

## 1. INTRODUCTION

Solar energy is an exceptionally promising renewable source of energy, with solar panels being the primary technology to use sunlight for converting into electricity [1]. Whereas many areas with high irradiation, such as the Sun-Belt region, have to deal with a lot of dust and less water resource, which results in power loss and lower efficiency of solar panels [2]. Creative solutions address these challenges, such as automated cleaning systems, anti-soiling coatings, and water-efficient cleaning techniques [3].

Most Used Methods of PV Panel Cleaning Manual cleaning, vacuum suction cleaning, wiper cleaning, and ESP-based cleaning are common cleaning methods being used on the panels. All these methods need some active human intervention [4] but can be optimized with intelligent control algorithms to save time and increase coverage efficiency. The control system must also be equipped with remote monitoring and diagnostics to monitor the robots' performance and make modifications as needed [5].

Solar panels cleaning robots can be categorized into two types: manually operated cleaning robots and autonomous cleaning robots. Manual operation robots are under constant supervision from the user, and one relies on visual inspection and regulation of cleaning range and speed. Autonomous cleaning robots are equipped with multiple sensors, following pre-mapped paths to clean the panels [6]. There are two variations of automatic drive cleaning robots, namely continuous cleaning and mobile robots that autonomously navigate along predefined tracks. Robotics would nullify human labour work and hence become economical and self-sufficient [7]. The output of the automatic-cleaning system is about 30% better than the input of dust accumulated Solar PV modules [8].

By the above data, solar panels are the one of the best sources of renewable energy, but it requires maintenance to generate electricity efficiently. To maintain constant electrical efficiency cleaning photovoltaic solar panels is required. The present condition for cleaning solar panel uses man-power, replacing the manpower with a robot which is more efficient in cleaning and also reduces time consumption compared to previous methods.

## 2. METHODOLOGY AND DESIGN

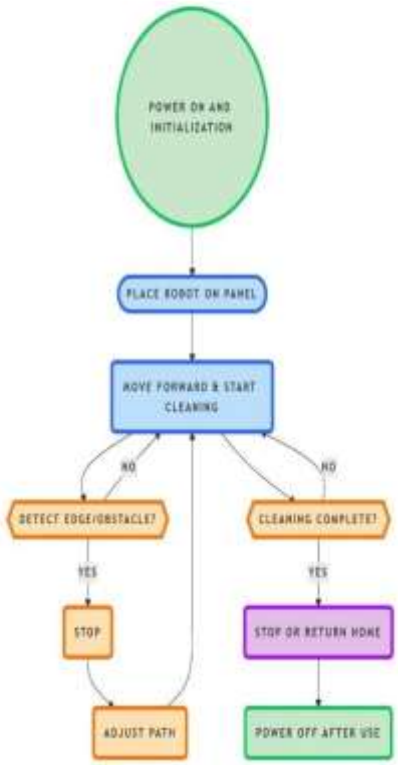


**Fig -1**: Flowchart of Methodology

## 2.1 SYSTEM OPERATIONS:

### 2.1.1 Power Initialization

The system is powered by a rechargeable battery and initializes all components, including ultrasonic sensors, DC motors, and other peripherals. It checks basic operational readiness, such as sensor connection, motor response, and power level. The robot is manually placed at the starting point of a solar panel, and the microcontroller activates the two-wheel drive (2WD) system using DC motors.

### 2.1.2 Placement and Starting Position

- The robot is manually placed at the starting point of a solar panel.
- The microcontroller triggers initial movement by activating the two-wheel drive (2WD) system using the DC motors.

### 2.1.3 Movement and Dry-Cleaning Process

The robot moves forward across the solar panel, continuously monitoring the distance to the panel edges. When the ultrasonic sensors detect an edge or obstacle, the microcontroller stops the motors or reverses direction. The robot wipes the surface of the solar panels with soft cotton cloth strips attached to the front and rear, ensuring dust and light debris are removed.

### 2.1.4 Edge Detection and Path Adjustment

Edge detection and path adjustment are performed by stopping the robot immediately to avoid falling off the panel or turning or reversing direction depending on the programmed cleaning pattern. Obstacle detection and avoidance are optional enhancements, with the microcontroller temporarily stopping movement or attempting to navigate around the obstacle if pre-programmed. If navigation is not possible, the robot halts and alerts the user.

### 2.1.5 Obstacle Detection and Avoidance

- If the robot encounters a raised obstacle (such as mounting frames or connectors), the ultrasonic sensors detect it.
- The microcontroller:
  - Temporarily stops movement.
  - May attempt to navigate around the obstacle if pre-programmed to do so.
- If navigation is not possible, the robot halts and alerts the user (optional, if a buzzer or communication module is present).

### 2.1.6 Completion and Return

After the entire cleaning area is covered, the robot can stop at the final position or return to the starting point. If a remote control or manual override is included, the user can start/stop the robot or manually control the movement.

## 2.2 OPERATIONAL PURPOSE:

The proposed solar panel cleaning robot is meant for vacuuming solar panels silently. This will be done by easing the surface with the aid of a soft cotton cloth that rubs the panel and picks up dust, dirt, and debris that could decrease the efficiency of the solar panels.

The system is to:

- Improve efficiency of the solar panels by keeping the panel cleaned.
- Little or no expenses on manual labour due to automatic cleaning.
- Non-water using system thus applicable in areas of water scarcity.
- Prevention against panel damage by gently wiping with soft cotton cloth.

## 2.3 WORKING PRINCIPLE:

### 2.3.1 Mobility and Navigation:

The robot promotes movement using a 2WD drive chassis with a DC motor. An ultrasonic sensor is used to sense the distance with the edge and any obstacle that might surface, thus helping in preventing the robot from falling off the panel or crashing against obstacles. The microcontroller unit gets inputs from ultrasonic sensors and control motors of forward, stop, and turn.

**2.3.2 Dry Cleaning Process:** While the robot goes, soft cotton cloth strips are attached to the front and rear sides of the robot. The fabric strips clean the surface in all directions and collect dust and minor debris while the robot moves. Somehow, these soft sweeps don't require any detergents or water, which makes them even more eco-friendly and easier to maintain.

### 2.3.3 Control and Automation:

The microcontroller is the main controlling device, capturing ultrasonic sensor signals and controlling DC motors' movement. It takes action to stop, turn, or reverse at intervals to traverse the panel's surface area. The system's programming allows time management or manual bypass via external controls when needed.

## 2.4 TYPES OF CLOTH FOR CLEANING SOLAR PANEL:

| Panel Type | Suitability for Dry Cleaning Robots |
|---|---|
| Polycrystalline | Suitable |
| Monocrystalline | Highly Suitable (smooth surface) |
| Thin-Film | Suitable, but delicate - handle with care |
| Glass-Covered Panels | Highly Suitable |

**Table -1:** Table of clothes used for the cleaning process

## 2.5 KEY HARDWARE COMPONENTS:

| Component | Purpose |
|---|---|
| Microcontroller Unit | Main control system, processes sensor data and controls motors |
| Battery | Provides power for all components |
| Ultrasonic Sensor | Detects edges and obstacles to guide robot movement |
| 2-Wheel Drive Car Chassis | Provides mobility across solar panels |
| DC Motor | Drives the wheels to move the robot |
| Soft Cotton Cloth | Attached to the robot, gently wipes the panel surface to remove dust |

**Table -2:** Table of components used for robot

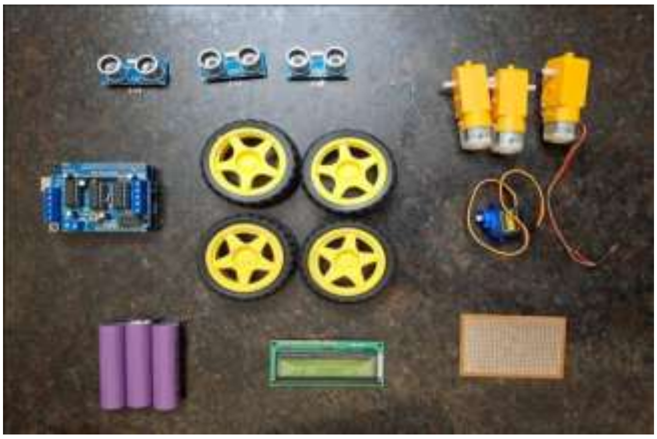

**Fig -2**: Components used in robot

## 2.6 CONTROL PROGRAM:

1. This Arduino program controls the solar panel cleaning robot, which displays battery voltage and can detect obstacles using ultrasonic sensors. While cleaning by moving forward with a rotating brush, it avoids obstacles by stopping, reverse driving, and turning.

**Fig -3**: Ardiuno program for robot

2. The program is a combination of motor controls, sonar sensors, and an LCD display that control the movement of the cleaning robot for the solar panels. This program reads the distance sensors and the battery voltage, displays the data on the LCD, and commands cleaning and working movement controls.

**Fig -4**: Ardiuno program for robot LCD display

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## 2.7 BASIC TYPES OF SOLAR PANEL:

**1. Polycrystalline Solar Panels**

The panel is cost-effective, easy to source, and suitable for testing and demonstration. Its surface texture is slightly rougher than monocrystalline panels but smooth for cleaning robots.

**2. Single Crystal Solar Panels**

- They are efficient panels with smooth and unblemished surfaces.
- They are more expensive yet usually seen in home solar installations and smaller-scale projects.
- Cleaning Challenge: Since the surface is cleaner, they are less prone to collecting dust between cells, which facilitates cleaning by robots with soft cloth cleaning systems.

**3. Thin Film Solar Panels**

- Flexible and lightweight.
- Ultimately very smooth surfaces and not so commonplace for massive solar farms.
- Used in niche applications like rooftop and portable solar systems.
- Cleaning Challenge: Thin film panels are fairly fragile, making them ideal for soft cloth dry cleaning
- methods.

**4. Glass-covered Solar Panels**

Large solar farms and rooftop installations often use glass-covered panels, which are weather-resistant and suitable for wet and dry-cleaning robots. However, cleaning challenges include water spots, dust, and bird droppings, necessitating wet or dry wiping methods.


**Fig -5**: types of solar panels

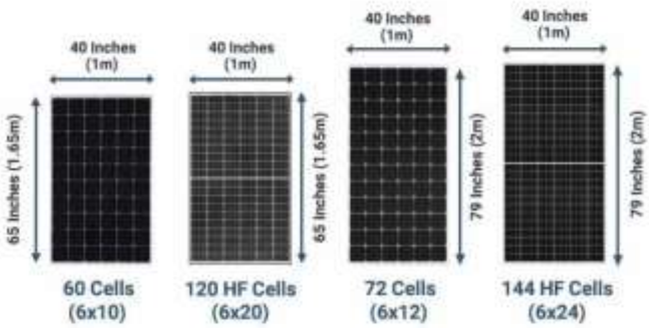


**Fig -6**: dimensions of solar panels

## 2.8 CALCULATIONS:

**2.8.1 Inputs in centimetres (cm):**

- 1 foot = 30.48 cm
- Panel length = 5.5×30.48 =167.64cm
- Panel width = 3.2530.48 = 99.06 cm

**2.8.2 Total area to clean:**

- Area = 167.64×99.06=16597.70167
- 99.06 = 16597.70 cm²

**2.8.3 Cleaning path and speed:**

- Cleaning cloth disc radius = 5 cm
- Disc diameter = 10 cm
- Speed = 5 cm/second

The robot would clean one horizontal strip (10 cm wide) at a speed of 5 cm/second.

**2.8.4 Number of passes needed in length:**

- Total panel width = 99.06 cm
- Number of passes = 99.06÷10=9.90699.06 /10 = 9.906
- it approximately 10 passes to cover the full width of solar panel.

**2.8.5 Time for each pass:**

- Length = 167.64 cm
- Time for 1 pass = 167.64/5=33.528167.64 /5 = 33.528 seconds per pass

**2.8.6 Total cleaning time**

- Total cleaning time = 33.528×10= 335.28 seconds
- Conversion to minutes = 335.28÷60 = 5.59 minutes

**2.8.7 Voltage and current consumption:**

**Average voltage (V)**

19.07+19.22+19.31+19.28/4 =19.22 V

19.07 + 19.22 + 19.31 + 19.28/4 = 19.22V

**Average current (mA)**

134.3+145+141.6+131.94 =138.2 mA

134.3 + 145 + 141.6 + 131.9/4 = 138.2 mA

**Convert to Amps**

138.2÷1000=0.1382 A

**2.8.8 Total energy consumption per cleaning cycle:**

**Power (P)**

P = V×I =19.22×0.1382≈2.66 Watts

**Total energy consumption for 5.6 minutes:**

2.66×5.6=14.9 Watt-minutes

**Convert to Watt-hours**

14.9/60=0.248 Wh≈0.25 Wh.

## 2.9 POWER AND TIME CONSUMPTION TABLE AND GRAPH:

| Time | Before Dust | | During Dust | | After Cleaning | |
|---|---|---|---|---|---|---|
| | V(v) | I (mA) | V (v) | I (mA) | V(v) | I (mA) |
| 11.00 am | 19.07 | 136.23 | 19.07 | 54.31 | 19.07 | 134.3 |
| 12.00 pm | 19.22 | 142.70 | 19.22 | 56.39 | 19.22 | 145 |
| 13.00 pm | 19.31 | 140.53 | 19.31 | 56.91 | 19.31 | 141.6 |
| 14.00 pm | 19.28 | 132.95 | 19.28 | 53.92 | 19.28 | 131.9 |

**Table -3:** Current and Voltage Table

| Time | P ( W ) | | |
|---|---|---|---|
| | Before Dust | During Dust | After Cleaning |
| 11.00 am | 2597.85 | 1035.65 | 2561.10 |
| 12.00 pm | 2742.76 | 1083.89 | 2786.90 |
| 13.00 pm | 2713.62 | 1098.90 | 2734.30 |
| 14.00 pm | 2756.00 | 1039.60 | 2543.03 |

**Table -4:** Power and Time Table

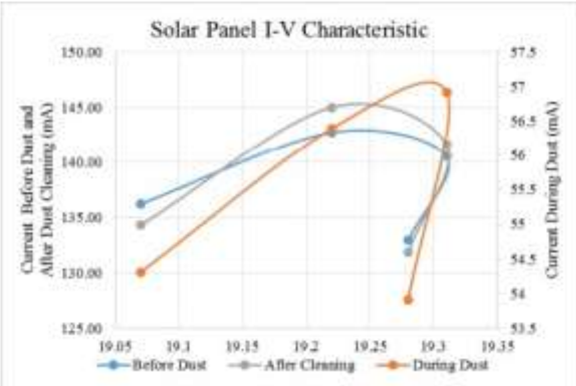


**Fig -7**: COMPARISON OF CURRENT BEFORE AND AFTER CLEANING

## 2.10 RESULT:

A solar panel cleaning robot has been developed and tested to effectively clean solar panels using a dry-cleaning mechanism with soft cotton cloth. The robot's movement is controlled by a microcontroller unit, which receives real-time distance data from ultrasonic sensors. The two-wheel drive system powered by DC motors ensures smooth movement across the panel surface. The robot effectively removes dust and loose dirt without water, making it suitable for arid and water-scarce regions. The robot demonstrated autonomous dry-cleaning capability, improved generation efficiency without manual intervention or external water sources panel cleanliness, and maintained energy generation efficiency without manual intervention or external
water sources.

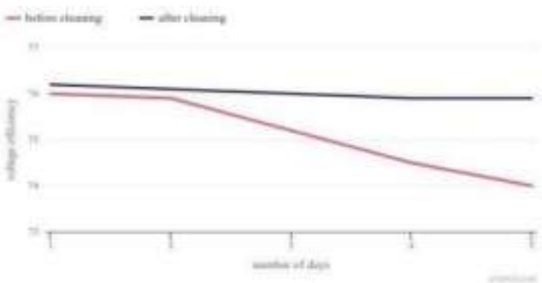

**Fig -8**: Result of voltage efficiency before and after cleaning

**Fig -9**: progressing robot construction

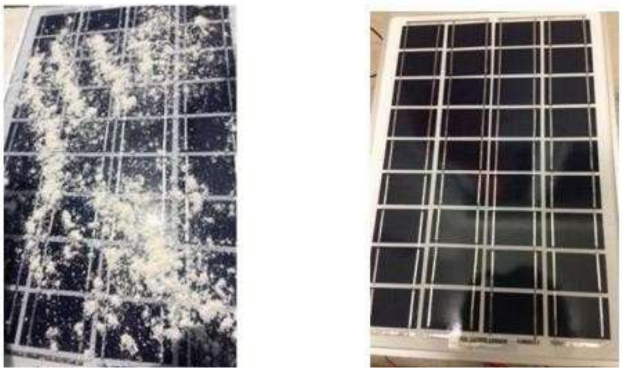

**Fig -10**: solar panel before and after cleaning

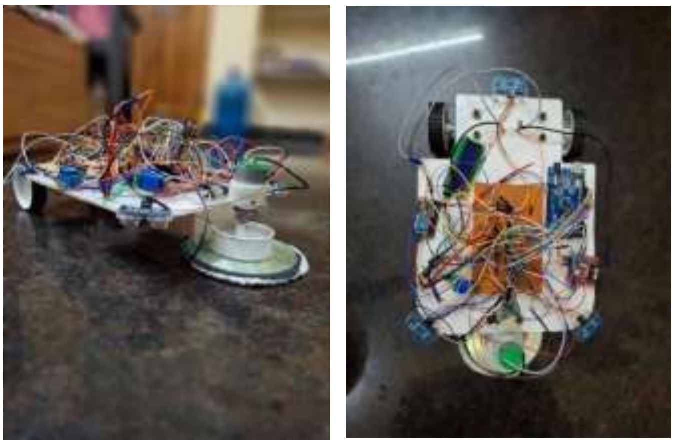

**Fig -11**: Robot prototype for cleaning solar panel

### 3. CONCLUSIONS

The project involved the design of the solar cleaning autonomous robot that will minimize the dust accumulation on photovoltaic solar panels. It is a two-wheel drive, ultrasonic sensors for edge detection, and an Arduino-based microcontroller system that controls everything in respect to movement, cleaning, and so forth. The soft cotton cloth strips clean the dust and the dirt off it; thus, no water is required. The ultrasonic sensors in the robot detect the edges of the panels and the microcontroller controls its movement. The system is cost-effective and environment-preserving and would contribute to the sustainability of solar power installations.

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