WHITE PAPER

DESIGN AND DEVELOPMENT OF SOLAR PANEL CLEANING ROBOT WITH AN ON-DEMAND WET CLEANING SYSTEM

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Abstract

Solar energy is a prominent source of non-conventional energy across the globe, and solar energy harvesting is a vital need today. Both domestic and industrial sectors adopt solar panels, also called photovoltaic (PV) panels to generate solar power as a part of green initiatives. The performance of the solar panels depends on the amount of radiant energy that reaches the PV cells. Several factors influence achieving optimal performance. "Soiling," commonly caused by dewdrops, dust, humid weather, bird dropping and rain, is one such critical factor which causes large drops in solar panel efficiency and power production. It is. Hence, there is a need to clean solar panels regularly. The rise in large solar panel facilities across remote dry areas that experience high temperatures implies a need for frequent cleaning. At present, a labor-intensive and monotonous cleaning process is deployed, resulting in operations that yield low efficiency. The robotic cleaning system can help address these challenges. With their cleaning heads, robotic cleaning systems can navigate entire solar panel arrays and provide a thorough cleaning while using resources efficiently. This paper discusses the design and development of a solar panel robot with its autonomous features.

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Introduction

There is a significant increase in the importance of solar energy harvesting as part of green initiatives globally. Infosys leads many sustainability initiatives and has more than 70 solar plants with a cumulative installed capacity of over 40MW across India. A huge challenge faced in solar power generation is the reduced yield in PV panels due to 'soiling.' Frequent cleaning of solar panels is required to address the problems caused by soiling. At present, the manual cleaning methods used in solar farms across Infosys campuses are high cost. To harvest 1MW of solar energy requires over 9000 square meters of space and 4000 solar panels. Based on the setup type, the solar farm needs labor-intensive maintenance, which can lead to unsafe working conditions owing to the hot, dry weather. Further, such maintenance may not clean enough to keep the solar panels functioning at maximum capacity. Hence, manual cleaning is unfeasible for large solar farms that require frequent cleaning.

Moreover, manual cleaning requires large amounts of water, typically between 7,000 to 20,000 liters for every MW of energy produced. A weekly cleaning schedule can, therefore, be a significant drain on local water resources. We must also consider the impact of rainwater on the solar panels. It is estimated that a minimum of 20 mm rainfall is necessary to clean panels and anything lower than that ends up soiling the panels by mixing with the existing dust. Undoubtedly, a robotic cleaning system with a cleaning head is the preferred solution to conserve resources and ensure a good return on investment.

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Soiling

Currently, we have an environment polluted with atmospheric aerosols. The deposition of such particles on photovoltaic (PV) panels is termed as "soiling." Soiling shading is another parameter which reduces panel performance and can be categorized as soft shading (air pollution) and hard shading (solids such as bird droppings and accumulated dust that block sunlight falling on the solar cells).

Dust, emanating from various sources including air pollution, weather changes and smoke accumulate over time and aggravate the soiling effect. It impacts the overall energy produced by solar panels.

Bird droppings, a common occurrence, block sunlight on the spot below where they drop on the panel. Consequently, no electricity will be produced from that spot; in fact, it acts as a resistor blocking power generation and causes the area to heat up and damages the panel. If left untreated, the damage spreads to the surrounding areas and gradually destroys the entire panel.

A summary of the negative impact of soiling -

- Lowered power output
- Decreased panel life by erosion
- Decreased average efficiency by about 25%
- Reduced efficiency from 2% to 50% depending on the type of dust
- Reduced power 0.2% every day in dry weather
- Reduced panel efficiency after a light rain

Figure 1: Bird dropping on the solar panel

Figure 2: Hotspot formed due to improper cleaning of panel and the thermal effects around the hotspot

Market analysis

We studied the product and technology schema of existing solar panel cleaning robotic systems to arrive at the most innovative cleaning system, which can deliver autonomy, high performance, and significant cost benefits. A few products available in the market today are -

Ecoppia E4*

Ecoppia, an Israel based company, is known for their robot, the E4. The main features of the E4 include two microfiber brushes that move vertically along and horizontally along the panels. The robot powered by a solar panel features a dry cleaning system. The E4 mainly targets solar farms in arid climates that would need frequent cleaning and which have limited access to water. Its features:

- A solar-powered system
- A large production based in India with multiple deals with large solar farms in India and Israel.

The drawbacks:

- Limited to fixed tilt panels
- Requires one robot per row of solar panels to clean
- Cannot clean stubborn soiling spots as it does not possess a wet cleaning option
- More time to clean due to a vertical cleaning mechanism

SunPower*

SunPower manufactures both solar panels and cleaning robots for them. Their robots clean an entire row of solar panels using an average of half-cup (4 ounces) of water per panel. It is lightweight and can be easily mounted on solar panels, only requiring a water supply and a crew to mount and dismount the robot. The SunPower robot is currently available exclusively for SunPower's Oasis tracker panels, cleaning them when they are parallel to the ground.

The drawbacks:

- Can only clean tracker panels since it needs to be positioned parallel to the ground
- Can be used only on SunPower's solar panels

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Indisolar*

Indisolar's robot utilizes a long roller brush with nylon bristles that brushes dirt off the solar panel and expels it through slots in the top panel and out the side of the robot. It features a solar panel mounted on top to charge itself and does not use water to clean solar panels. Indisolar targets rooftop farms and homes with solar panels.

Its features:

- Mounted on a row of solar panels
- A solar-powered system
- Minimal maintenance requirements
- Able to clean panels mounted up to a 250° angle

The drawbacks:

- No efficient method to remove dust
- Only dry cleaning does not guarantee a sufficient clean

GEKKO*

Serbot, a Swiss innovation company, develops GEKKO solar farm robots. The GEKKO robots are designed to clean utility-scale solar firms using a spray of water, roller brushes and a squeegee. The robots use suction cups and motors to traverse the row of solar panels. Serbot currently targets only solar farms with wide rows of panels.

Its features:

- Easy handling with radio and joystick
- Excellent cleaning quality with rotating brushes and demineralized water usage
- Adaptable and can clean different widths of panels with the flexibility to select the number of brushes
- Productivity of up to 2000 m2 per hour
- GEKKO solar farm works up to inclinations of 30°
- The robot can overcome obstacles of 60 cm in width

The drawbacks:

- Requires a car or robot to be mounted onto the solar panels.
- Lacks autonomy

Miraikikai*

Miraikikai is a portable robot that uses bristles to brush the dust off solar panels. The robots do not use water and operate using sensors that detect. Cleaning power or the recovery rate of solar power generation of the robot equals that of manual cleaning. The robot uses on board sensors and autonomous control systems to sweep automatically across the solar panel array.

Its features:

Optimized design makes it lightweight and easy to carry

- Specialized mechanism to cross the gaps between the solar panel arrays

The drawbacks:

- Can clean only one panel at a time
- Charge only lasts two hours
- Slow cleaning of solar panel arrays

** The name, logo and trademarks used here are for benchmarking only, and more details can be found in reference (Section 14) links provided in this paper.*

Design of robot

Initial Experiments

We studied many cleaning methods to identify the most effective approach considering critical performance parameters. A few methods of cleaning include:

- Dusting with cloth
- Scraping with fingernail
- Scrubbing using brushes
- Blowing dirt with air
- Spraying water and letting it dry
- Spraying water and wiping it from the panel

The soiling considered for the study included:

- Dust
- Bird and bee droppings
- Pollen
- Hot spots

The test results showed that manual cleaning with water and wiping was the most effective way to clean. Dry cleaning of the dust could not remove the leftovers of bird and bee droppings from the solar panel. Dry cleaning the entire solar panel initially followed by spraying water and wiping gave the best results.

The sequence of operations to be followed to achieve the best results is -

- A rotating roller brush traversing the length of the solar panel arrays to remove the top layer of dust.
- An intelligent vision-assisted location-specific wet cleaning to achieve high quality cleaning
- A secondary circular brush assisted by water spray to wet clean specific locations or tough spots

The robotic systems that are available in the market do not provide the required features with optimal use of resources like power and water. Hence, Infosys developed a next-generation solar panel cleaning robot with an on-demand wet cleaning system.

The Infosys system provides a blend of wet and dry cleaning options. Fast and efficient dry cleaning along the solar panel array integrated with a smart wet cleaning system yields an economical and high-quality solution. The key requirements are that it should offer optimum cleaning options based on the demand and extent of soiling with vision-assisted wet cleaning, optimizing water usage and requiring minimal maintenance.

Design specifications

Our detailed study helped us arrive at specifications for an optimal robot configuration -

- Linear speed of 0.2 meters per second
- Cleaning rate of 24 square meters per minute
- Weight of less than 30 kilograms
- Utilize a 20Ah 24V DC lithium ion batteries with an optimal charging method
- Use a maximum of 75 watts of power
- A bi-directional cleaning system
- Smart vision-assisted dry and wet cleaning
- Intelligent dirt collection
- Solar tracking

These specifications will result in an advanced system that is not offered by any robotic system vendor today.

Business problem

- Soiling threatens the productivity of solar panels and requires cleaning to be scheduled
- Cleaning the solar panel is challenging as it is mostly done under the sun
- The current mostly manual cleaning process is monotonous and repetitive and needs to be automated

The present manual cleaning is inefficient, expensive and demands high efforts .

Infosys solution

- Development of a robotic platform for solar panel cleaning with dry and wet cleaning capabilities
- Industry grade robotic platform
- Unmanned cleaning system
- Smartly integrated solar robot platform
- Robotic system is on-demand and integrated with a vision system for effective cleaning

Business benefits

- 24X7 automated cleaning operation
- Frees up bandwidth
- Remote cleaning
- 5% increase in power generation expected
- Labor reduction by more than 60%
- On-demand and scheduled cleaning programs

Mechanical systems

The robot structure is made of a combination of aluminum structure, machined and sheet metal components.

The robot consists of a single replaceable dry brush for the dry cleaning cycle and an integrated wet cleaning head mechanism with a uni-guided rack and pinion drive mechanism for the wet cleaning cycle.

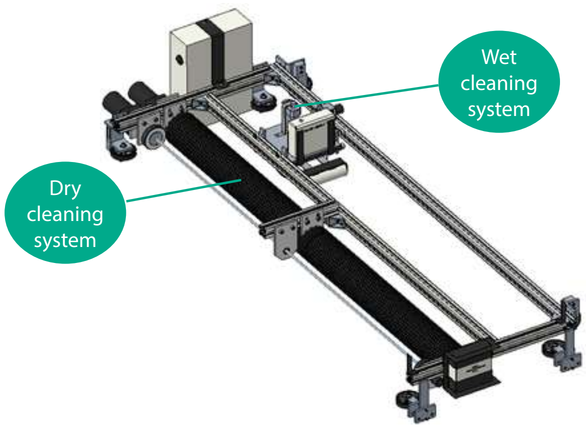

Figure 3: Mechanical complete system

Working principle of solar panel cleaning robot

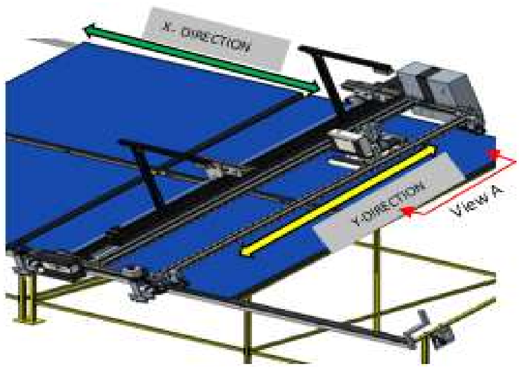

Figure 4: System on Solar panel frame

The robot is designed to move on the solar panel frame in the longitudinal direction (X-Axis) along the rows of the solar panel; dry cleaning is done in the longitudinal direction, and the wet cleaning module can move in the vertical direction (Y-Axis).

The wet cleaning head can be armed and disarmed with an actuator (Z-Axis), as shown in View A. The robot can be programmed to position at any point on the array of solar panels using X and Y-axis control.

Working principle of a dry cleaning system

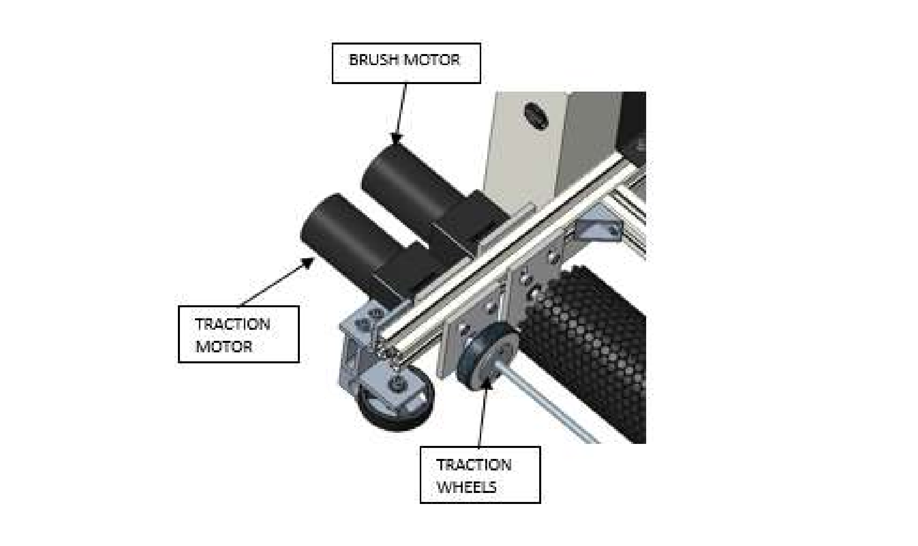

Figure 5: Dry cleaning system assembly

The dry brush is of 2m long with a helical bristle arrangement for self-cleaning of accumulated dust particles. It has an inner core made of nylon and an aluminum shaft running through the brush core; the shaft is coupled to the brush motor using couplers at both ends. The traction wheels or driving wheels on both ends are driven by a single shaft, which is coupled to the traction motor. The speed of the traction motor is equal to the dry cleaning rate.

Working Principle of a wet cleaning system

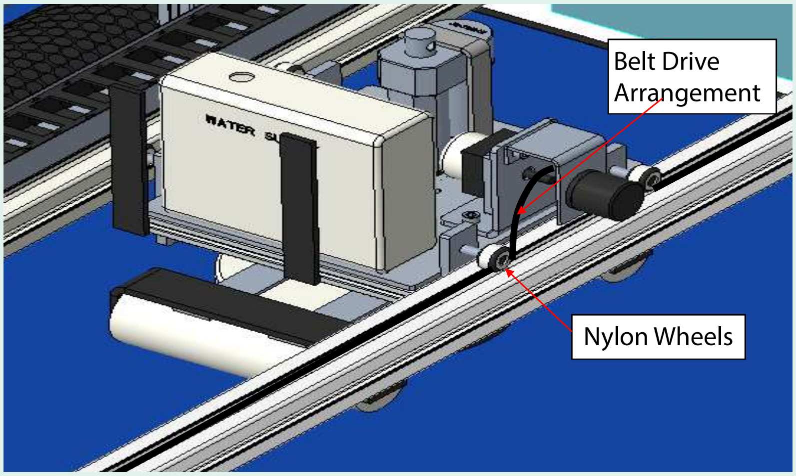

Figure 6: Wet cleaning system assembly

The wet cleaning system comprises a belt-driven motor, which engages a pulley for longitudinal movement. The system is guided with nylon wheels supported at the corners of the system, as shown in Figure 6. The belt and pulley arrangement is modular and can be made tense when it becomes slack over time.

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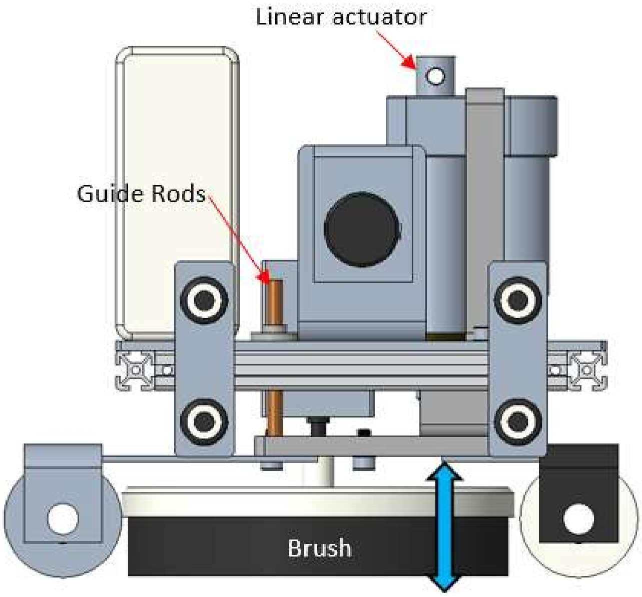

View A

The wet cleaning head can be armed and disarmed with a motorized actuator (Z-Axis). This will help optimize the pressure exerted by the circular wet cleaning brush on to the solar panel. The Z-movement can be controlled by software to exert optimal pressure on the solar panel array.

Design phases

The solar panel cleaning robot is envisioned to evolve in three phases with strategic advances in each of the phases. At the end of each phase, we expect a minimum viable product (MVP). The details of each of the MVP have been given below:

MVP 1.0 – Uni-directional cleaning head with wet and dry cleaning

- Uni-directional cleaning head mechanism
- On-demand dry and wet Cleaning
- Integrated wipe system and water tank
- Single dry brush for dry cleaning
- Multi- rotary brush system for wet cleaning
- Dirt collector system
- Cleaning speed: 0.1m/sec
- Cleaning area: Minimum 50m2/minute
- Modular design
- Predefined cleaning pattern

MVP 2.0 – Bi-directional cleaning head with a vision system

- Bi-directional cleaning head mechanism
- On-demand dry and wet Cleaning
- Vision assisted smart wet cleaning
- Integrated wipe system and water tank
- Multi dry brush for dry cleaning
- Dirt collector system
- Cleaning speed:0.15m/sec
- Cleaning area: Minimum 75m2/minute
- Modular design
- Solar-powered battery system

MVP 3.0 – Integrated smart solar cleaning system

- Bi-directional cleaning head mechanism
- Smart vision assisted dry and wet cleaning
- Integrated wipe system and water tank
- Multi dry brush for dry cleaning
- Intelligent dirt collector system
- Cleaning speed:0.2m/sec
- Cleaning area: Minimum 100m2/minute
- Modular design
- Vision-based cleaning pattern
- IoT, Cloud, Data Analytics
- Solar tracking

Through the phases, the robot must be managed and controlled with various clean patterns and structural design included.

Similarly, the control system will go through optimized hardware, motor, sensors, algorithms and applications.

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Software architecture

The software stack consists of three main modules - programmable logic controller (PLC), SBC (on board CPU) and web server.

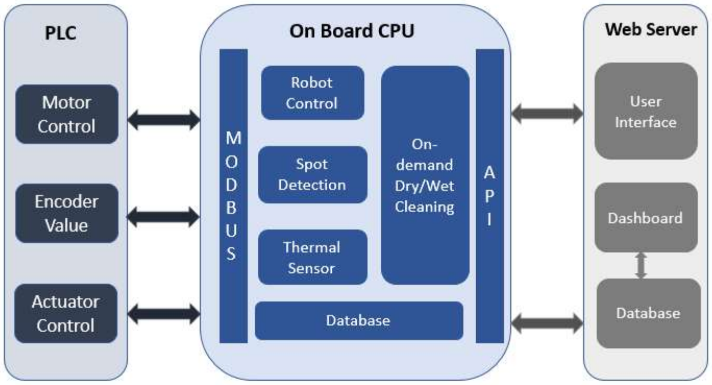

Figure 7: Robot Architecture

Web server

The main module for user interaction and robot management uses HTML, CSS, JavaScript and bootstrap for user-friendly interactions. This module controls all operations of the robot, including on-demand dry cleaning cycle, scheduled dry cleaning cycle and auto wet-cleaning. It also displays real-time status, robot battery status and performance through dashboards.

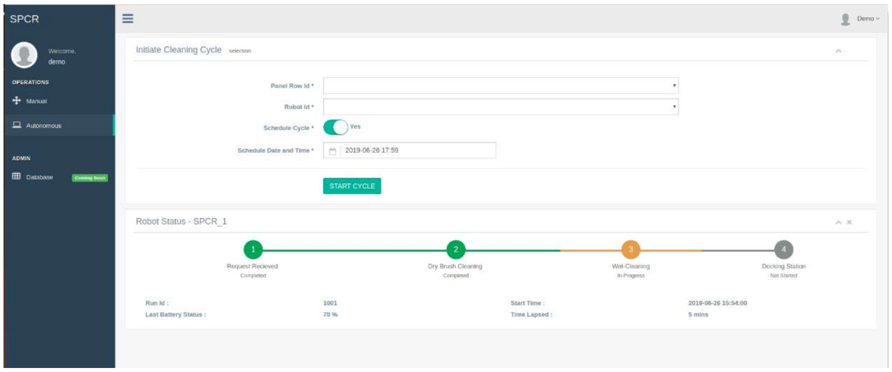

Figure 8: User Interface for a solar panel cleaning robot

The user can easily schedule a cleaning, even two months in advance or start immediately.

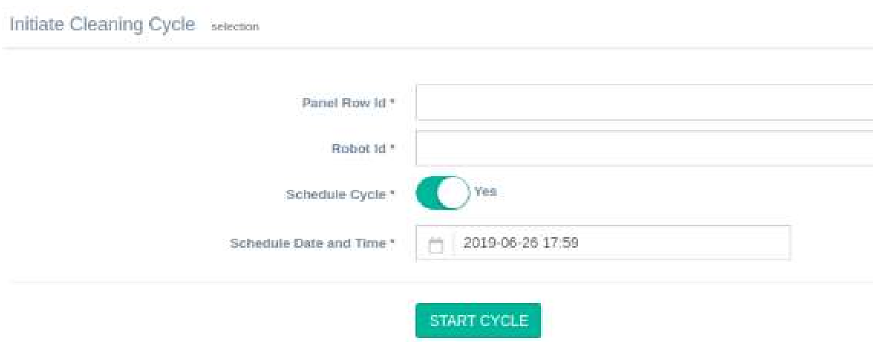

Figure 9: User Interface with the ability to start a scheduled cleaning process.

PLC Module

The PLC module contains the complete PLC ladder diagram for controlling all robot movements, including horizontal and vertical movement, wet module cleaning, wiper system cleaning, control commands from the RF module and user interface. It also controls dry brush actuation movement to ensure contact of brush with solar panel surface at all times for efficient cleaning.

On board CPU (SBC)

The SBC module contains the complete backend logic, including communication with the PLC using the Modbus protocol and user interface using APIs. This is implemented in both C++ and Python. C++ is used for faster communication with PLC and Python for the rest of the features.

Vision data is collected using the vision module and processed data with spot position defined in X, Y is collected using the MQTT protocol. These points are then passed sequentially, the closest point first, to the robot for cleaning using water. Once cleaned, the wiper system is activated for removing the excess water from the panel surface.

Data collected from the camera and thermal sensor are stored locally in a Sqlite3 database in the form of files. The data is later transferred to a web server over the network for analytics.

Once the process is started, the user can view the status of the robot in the status tab, which depicts completed, in-progress and not started steps.

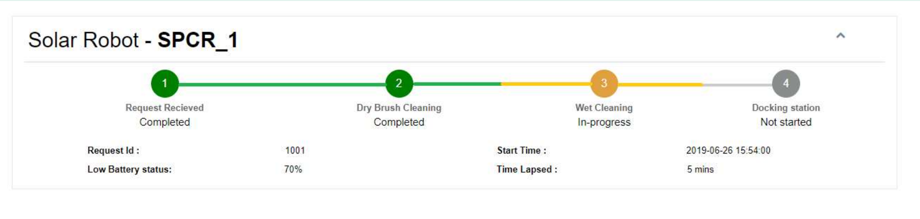

Figure 10: User Interface with ability to start scheduled cleaning process.

Vision system

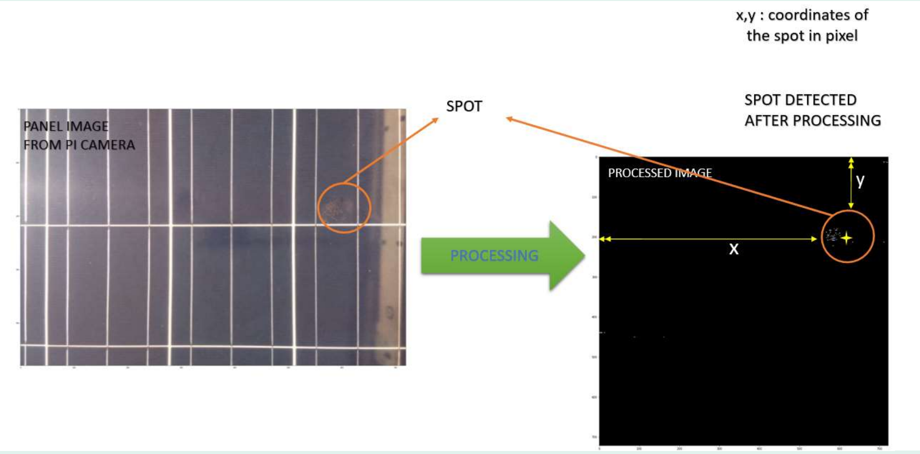

Figure 11: Depiction of spot detection by a vision system

The vision system is an on-demand unit of the solar panel cleaning robot (SPCR), which continuously captures images of cleaned panels. These images are passed through a pipeline, which performs pre-processing, followed by spot detection and identification. The final identified spots are passed to the control system for wet-cleaning processing.

Control system

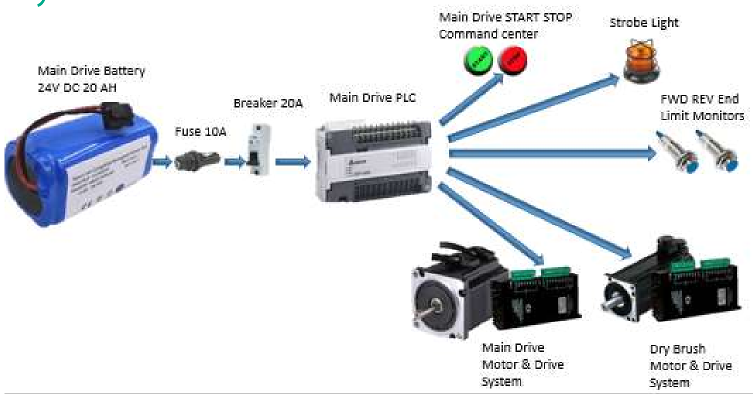

Figure 12: Circuit diagram that provides power supply to the main drive and dry brush

The robot is mounted on top of the solar panel array and battery power source and is well integrated with the system. The robot gets power from a 24V DC 20 AH battery, which utilizes 10A fuse and 20A breaker to protect from internal failures due to a short circuit before it reaches the main drive. The power enables the main drive motor and drive system, which sets in motion the motorized traction wheel and the strobe light to indicate that the robot is operational. When the traction motor starts to rotate, the traction wheel gains momentum and makes the robot move forward. When the robot moves forward, the dry brush motor starts to spin at the desired high speed and removes the dust particles from the solar panel. The wet cleaning system addresses the excess soiling on the panel through light scrubbing and wiping with wipers attached at the back. The main drive also has FWD/REV limit switches, which are enabled through the algorithm to identify when to stop the robot operation, upon reaching the limits of the traction or solar panel assembly end frames.

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Testing & validation

The complete system was tested for its durability and efficiency at a solar park in Infosys' Hyderabad campus. Some results from the system in comparison with the manual cleaning done at the park are shown in Figures 13 and 14.

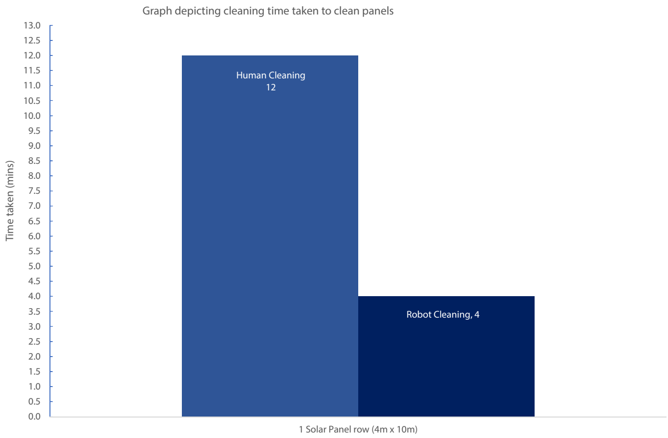

Figure 13: Graph depicting cleaning time taken to clean panels

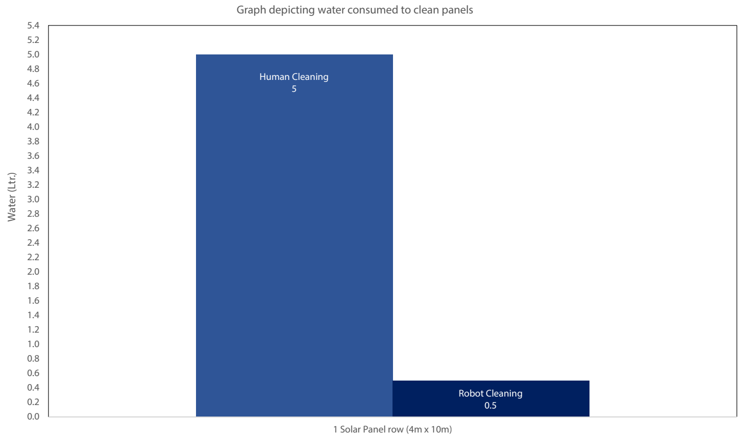

Figure 14: Graph depicting water consumed to clean panels

Limitations

- Panel structure needs to be firm and smooth for easy movement of the robot.
- Human interaction is required for placing the robot on a panel and moving from one array to another.
- Human interaction is required for charging the robot.
- System run-time is one hour only.
- Manual re-filling of water is required.
- Water level intimation is manual.

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Conclusion

The solar panel cleaning robot with an on-demand wet cleaning system was conceptualized with an autonomous system architecture powered with innovative cleaning head integrated with dry, wet and wiper systems. It is expected to be cost-effective over the long-term as it overcomes soiling that prevents the solar panels from operating at peak efficiency through regularly scheduled cleaning. Infosys will continue to innovate and improve the system.

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