# Autonomous solar panel cleaning robot using cable driven parallel manipulator

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# 1. Introduction

Solar panel cleaning and maintenance is an essential part of ensuring that the efficiency of the power system is maintained high throughout its life. Hence, it is important to effectively clean the system. Till now, most of the small scale solutions are manual. The large scale systems have an automated cleaning system built along with the system upon planning. Hence, for the existing large scale systems to be completely automated requires a lot of reconstruction investment which is unfavorable. A portable pick-and place semi-automated system can be developed in which the cleaner just fits in the device when necessary and the cleaning happens automatically. For this, a cable driven parallel manipulator system is used as it is convenient to place and transport by hand.

# 2. Mechanism

When deciding the mechanism, a lot of features have to be considered. All the considered factors are listed as follows:

## 2.1 Level of automation

Since the panels are not very continuous for putting a rail system, the level of automation can be a person fixing the device in each panel and then the robot cleaning the panel automatically after which it can be taken off from the system.

## 2.2 Degrees of freedom

The complete set of movements is planar on the cleaning surface. No rotation is necessary. Hence, 2 degrees of freedom is enough for this operation.

## 2.3 Number of cables

4 cables in 4 corners seems to ideal wrt load triangulation and the degree of freedom constraints.

## 2.4 Mounting mechanism

The following factors were considered for deciding the mounting mechanism.

- Easy mounting/unmounting. Flexibility in size of the system.
- Mounts should not cover any part of the panels. If they cover the panels, then that region cannot be accessed by the robot and cleaned.

Since the robot is expected to be flexible with various sizes, we can make the size of the boundary flexible by using ropes to constrain the boundary with a tensioning mechanism similar to a queue belt.

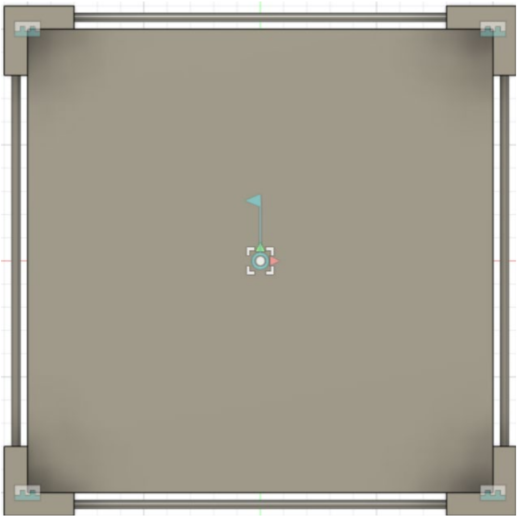

*Fig 1: Mounting mechanism of the panel - the square plate is the panel and the boundaries are constrained by ropes.*

## 2.5 Shape of cleaner

The shape of cleaner has been determined to be a square (rectangular) rather than a round/circular shape for easy access to the corners of the panels which are rectangular too.

## 2.6 Motor and pulley placement.

Though the most logical choice would be to fix the motors in the corners and not place it along with the robot due to the mass and inertia factor, placing them in the corners would lead to complexity in powering them as wires would have to be run along the edges and to the 4 corners which outweighs the inertia advantage. Hence, it was decided to place the motors along with the robot. With regard to the pulley, since it has to be connected to the motor, it also is connected along with it.

## 2.6 Inclination of the rope

There are 3 qualitative choices. Parallel, inclined with a positive angle or inclined with a negative angle(hanging). Inclining with a positive angle ensures that the cleaner is always in contact with the panel and hence, aids effective cleaning.

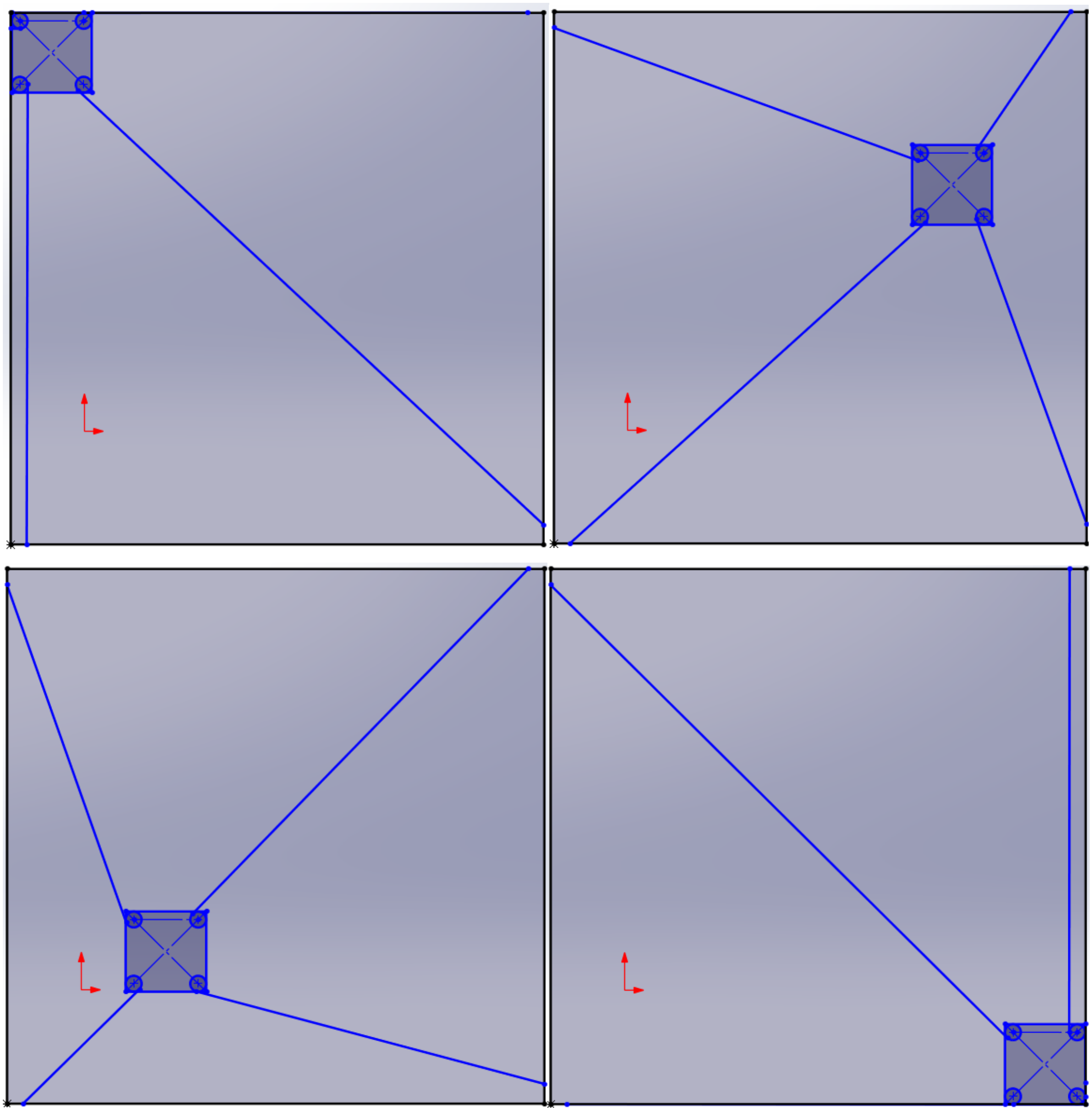

*Fig 2: Cleaning mechanism - in steps*

# 3. Motor Selection

## 3.1 Requirements

Since this is a robotic application, a stepper motor is an ideal choice. To determine the specifications and requirements, an initial case was assumed as follows

- The panel is a square panel.
- The panel is inclined at 20 degrees to the horizontal.
- The rope is inclined 20 degrees to the panel.
- Mass of the entire robot - 5kg.

- Neglecting friction will be a worst case scenario which can be assumed.
- The bottom 2 ropes will not take tension as they are in compression.
- Radius of the pulley - 10cm

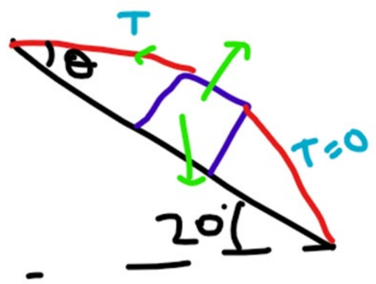


*Fig 3: Side view of the assumed use case robot.*

$$mg\cos\theta + 2T\sin\theta = N$$

$$2T\cos\theta\cos\frac{\pi}{4} = mg\sin 20^{\circ}(-friction)$$

$$\tau = T * r$$

where m is the mass of the robot, T is the tension in the upper rope, $\theta$ is the angle of inclination of the rope with the panel, r is the radius of the pulley, $\tau$ is the torque which will be on the motor.

Calculating this for the above use case, we get

$$\tau = 25\ kg - cm$$

## 3.2 Motor specifications

After rigorous analysis, INVENTO Nema 17 Bipolar Stepper Motor with Planetary Gearbox was selected for this application. Its weight is 450g, holding torque is 70 kg-cm and the gear ratio is 19:1.

## 3.3 Sensors

Since this is an automated application, we would need the following sensors to help in the automation

- Strain gauge - to measure the load in the rope and to check whether the the rope is taut.
- Optical encoder - to measure the amount of travel by the rope. This will help in determining the position of the robot at any instant of time.


*Fig 4: Image of NEMA 17 Bipolar Stepper motor*

# 4. Future work

The future work in this includes incorporating the motor and sensor selections into the CAD model and determining the mounting methodology. Also, the designs of spools and pulleys and their attachment with the motor can be done. Cleaning methodology and material selection for the same will have to be done before integrating every component and manufacturing the same. Software testing and tuning is an important part of the automation process and care has to be taken to accommodate components with respect to that as well.