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Sun Tracking, Self-Cleaning Solar Panel

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Introduction

Background

Renewable energy sources have been a pivotal innovation in progressing sustainable development. Currently, there are various renewable sources that are widely used around the world. Some examples include Solar, Hydroelectric, Geothermal and Wind. These renewable sources are the cornerstone of the SDG agenda for the world. Without clean and renewable energy, any initiatives to reduce the use of carbon based fuels and clean the environment would fall short. In essence, renewable energy sources contribute heavily to each and every sector in the world be it economic, social or political. As such, to improve the agricultural sector and introduce sustainability, renewable sources are crucial to jumpstart the process. However, despite constant innovation based upon these renewable sources, no innovation has truly ever aimed to improve upon them. Despite the clean energy, there are various problems with renewable sources. If solar power is used as an example, solar panels are expensive, require constant maintenance and primarily are only effective for a quarter of the day before the sun starts to set.

Problem Statement

As mentioned, improving renewable energy sources is essential for sustainable development. Considering Solar Power is the premier choice for most renewable projects, the primary problem with Solar Panels is that oftentimes they are mounted at inconvenient places and require a lot of effort to get to. They are typically placed really high up and far from reach as most panels work best at elevated heights. Hence, prolonged use of solar panels results in a decrease in efficiency due to an unclean surface that blocks out sunlight- Solar Panels can get dirty through dust and rain which cakes on mud to the photovoltaic surface blocking out sunlight and preventing energy generation.

Furthermore, Solar Panels are only effective from SunRise till Midday. As the Sun reaches the zenith and passes over its apex point, the Solar Panels are incapable of following this trajectory, resulting in lower power generation when compared to peak hours. Overall, if these two problems are solved simultaneously the efficiency of solar panels will definitely increase. Additionally, smaller solar panels will be more budget friendly due to an increase in power generation and product life time.

Objective

The objective of this project as as follows:

- To design and develop a working mechatronics system supporting solar tracking and self-cleaning functionality for Solar Panels.
- To Prototype a working Solar Tracking & Self Cleaning Solar Panel model

Scope

The scope of this report is entirely limited to utilizing basic mechatronics components and mechanical design to achieve a working concept proof of a Solar Tracking and Self Cleaning module. Overall, the final prototype must be able to achieve this functionality and successfully complete several tests to ensure its mechanisms are effective.

Note:

Certain concessions were made in the functionality of the product corresponding to the budgetary restrictions. In addition, owing to the limited availability of components at the expected accuracy level being affordable, the sensing capabilities of the prototype are not as effective in bright lights. A strong flashlight is used to simulate the presence of the sun and delay timers are used to ensure the prototype is in line with the expected motion.

Literature Review

Current Technology

360° Solar Tracking and Self-Cleaning Mechanism for PV Panels

Current improvements in solar PV module technology have concentrated on tackling efficiency and maintenance issues, particularly in dusty conditions like tropical nations. One innovative option is to combine sun-tracking sensors with automatic cleaning procedures. This combination strategy not only tracks the sun to improve radiation capture, but also keeps the modules clean, ensuring peak performance. The sun-tracking system rotates the PV modules 360° throughout the day, avoiding the need for additional sensors or synchronization components by taking advantage of the earth's inherent rotation.

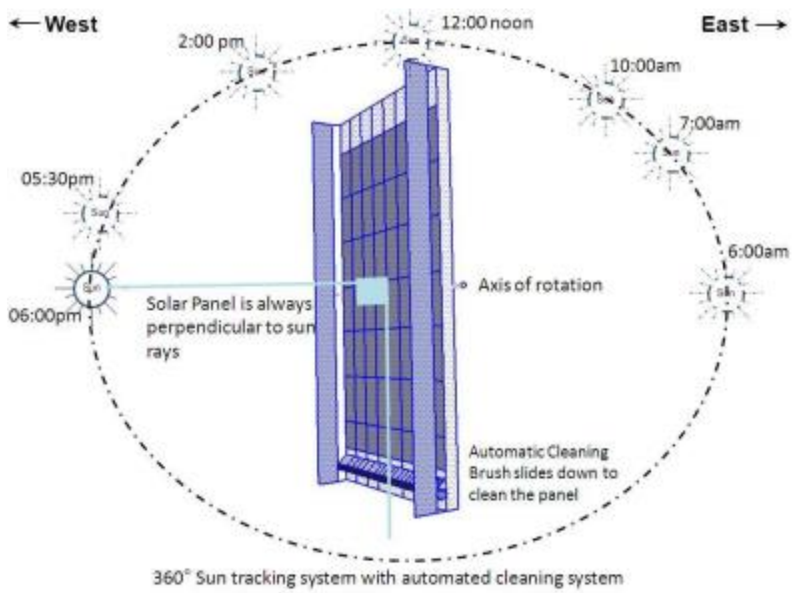


Figure 1 Rotation of panels throughout the day.(Tejwani et al., 2010)

This approach improves energy output by roughly 30% compared to stationary modules and 15% compared to single-axis tracking systems alone. The automatic cleaning system, which consists of sliding brushes, operates twice a day, significantly lessening dust formation, which can reduce the module's effectiveness by up to 50% if left uncleaned for one month. This dual-functionality system displays a significant boost in daily energy output and offers a cost-effective option for sustaining outstanding efficiency in solar PV modules.

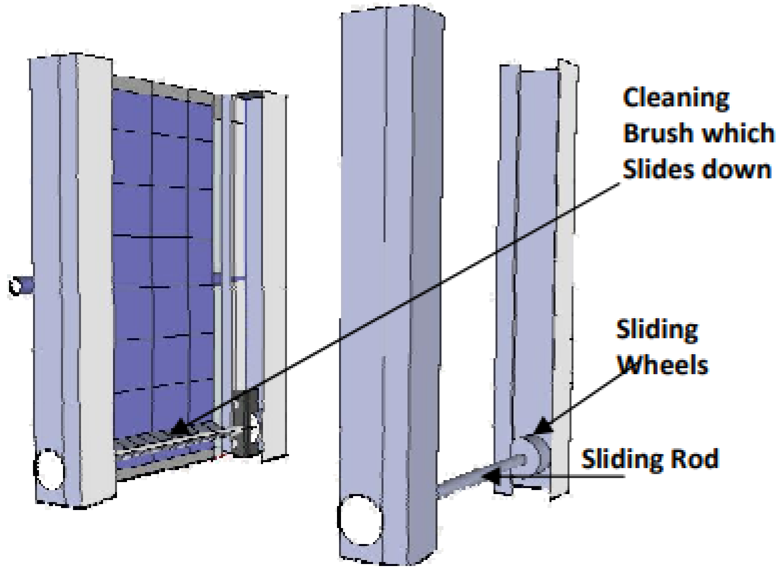


Figure 2 Sliding rod and wheels for cleaning mechanism.(Tejwani et al., 2010)

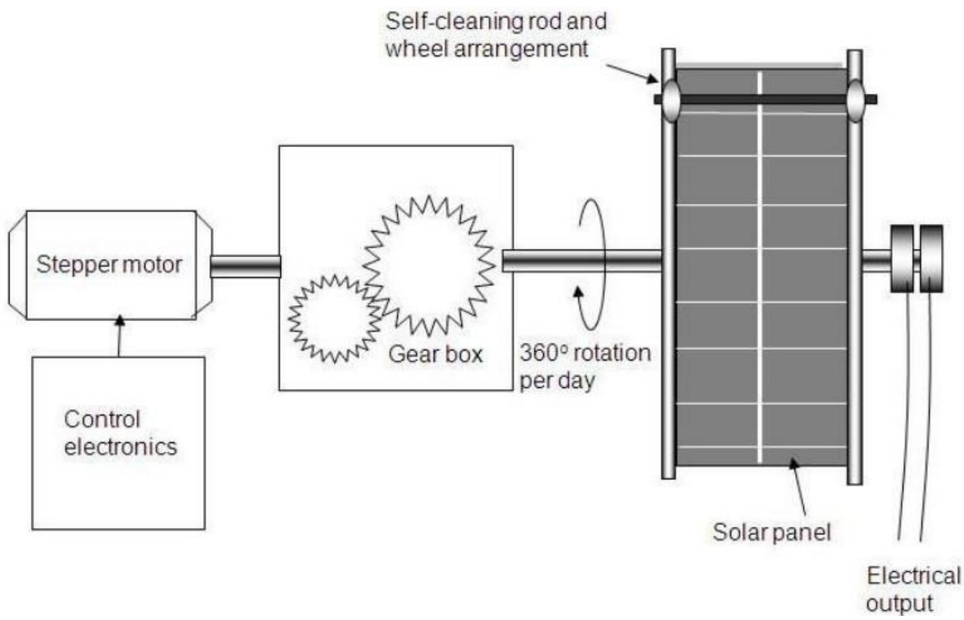


Figure 3 Schematic diagram of Sun tracking and automatic cleaning of solar PV modules.(Tejwani et al., 2010)

The mechanism to enhance solar PV module efficiency integrates a 360° sun-tracking system with an automated cleaning process. The sun-tracking system rotates the panels throughout the day, controlled by an 8051 microcontroller and a stepper motor with a gearbox, aligning them with the sun without additional sensors. The automated cleaning mechanism uses gravity-assisted sliding brushes to clean the panels twice daily, ensuring they remain free of dust and debris. This integration maximizes sunlight exposure and maintains panel cleanliness, significantly boosting energy output and reducing manual maintenance

Solar Photovoltaic Cleaning and Tracking Systems

Recent advances in solar photovoltaic technology have focused on increasing the efficiency and maintenance of solar panels by including self-cleaning and tracking features. One of the important developments is the creation of microcontroller-based systems that automate cleaning and tracking processes.

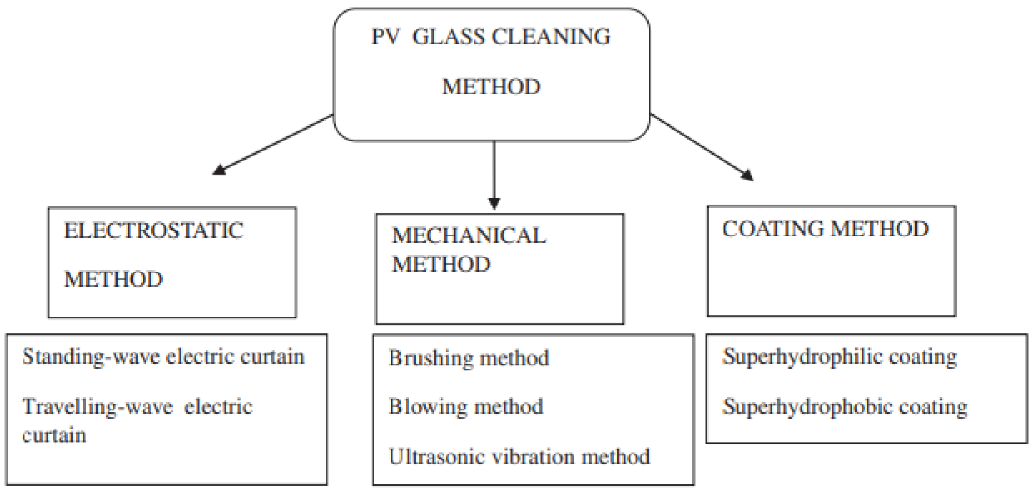


Figure 4 PV glass cleaning method.(Syafiq et al., 2018)

These systems guarantee that solar panels receive the most amount of sunshine by constantly shifting their orientation to face the sun. Furthermore, they have cleaning mechanisms to remove dust and other material that might develop on the panel surfaces, ensuring excellent efficiency. These automated solutions not only increase energy output, but they also cut manual labor and maintenance expenses connected with solar panels. The integration of such technologies is critical for improving the performance of solar energy systems, particularly in areas with high dust levels and changing sunshine conditions.

Several advanced methods currently used for cleaning and maintaining solar photovoltaic (PV) panels to enhance their efficiency. Key technologies include mechanical, electrostatic, manual, and coating methods. Mechanical methods involve techniques such as robotic cleaning, air-blowing, water-blowing, and ultrasonic vibration, which are effective but often consume substantial power. Electrostatic methods utilize electric fields to repel dust particles but also require electrical power. Manual cleaning, while straightforward, is not feasible for large-scale applications due to its labor-intensive nature. Among these, coating methods, particularly superhydrophilic and superhydrophobic coatings, stand out due to their low energy consumption and high efficiency in maintaining clean surfaces. These coatings alter the surface properties of the PV panels to prevent dust accumulation and facilitate self-cleaning through natural processes like water rolling off the surface. This integration of various cleaning technologies ensures the PV panels remain free of debris, thereby maintaining their `efficiency and extending their lifespan

Coating method

The coating method is employed to protect substrates from environmental factors by altering their surface properties, including adhesion, wettability, corrosion resistance, and wear resistance. Depending on the application technique, coatings can be applied using gasses, solids, or liquids. For hydrophobic surfaces, materials with low surface energy, such as silanes, silicones, nanoparticles, and polymers, are utilized due to their water-repelling characteristics. Conversely, to create superhydrophilic surfaces, materials with high surface energy are chosen for their excellent wettability properties. Superhydrophobic surfaces achieve self-cleaning by allowing pollutants and dirt to be removed by rolling droplets or surrounding air, while superhydrophilic surfaces facilitate pollutant removal through photocatalytic reactions. This coating method naturally provides self-cleaning capabilities, requiring low energy consumption and offering environmentally friendly, low-maintenance solutions.

Superhydrophobic coating method

The lotus leaf is the first biological surface to inspire the development of superhydrophobic materials. The exceptional superhydrophobicity and self-cleaning capabilities of the lotus leaf are attributed to its unique surface structures, which consist of a hierarchical array of micro-papillae, nano-wax clusters, and nano-wax tubules. These structures create a dual-scale roughness, with rough features approximately 10 μm in size and finer structures around 100 nm. This combination results in a high water contact angle (CA) of 161 ± 2.7° with a CA hysteresis of only 2°, as reported by Neinhaus and Barthlott. According to the Cassie-Baxter (CB) state, water droplets remain suspended above these hierarchical structures in a non-equilibrium thermodynamic state, enabling them to roll off the surface spontaneously and resulting in low hysteresis. The two essential criteria for achieving self-cleaning properties on superhydrophobic surfaces are a water contact angle greater than 150° and strong resistance to pollution.

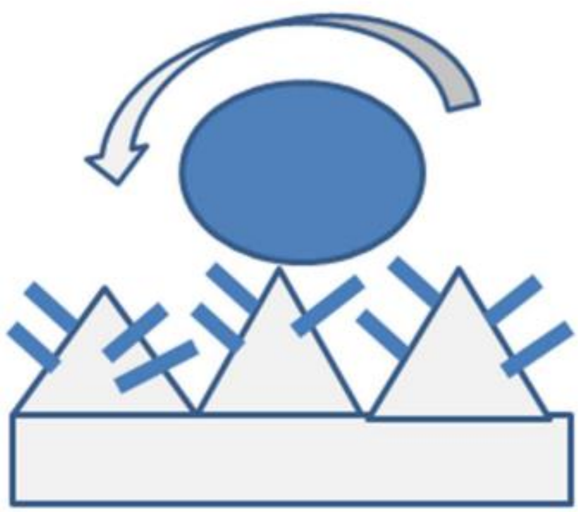


Figure 5 Lotus effect.(Syafiq et al., 2018)

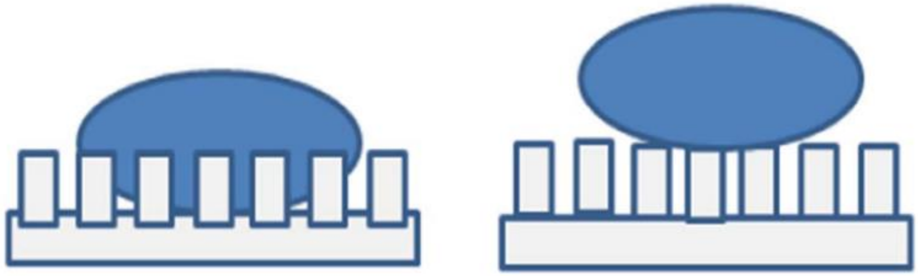
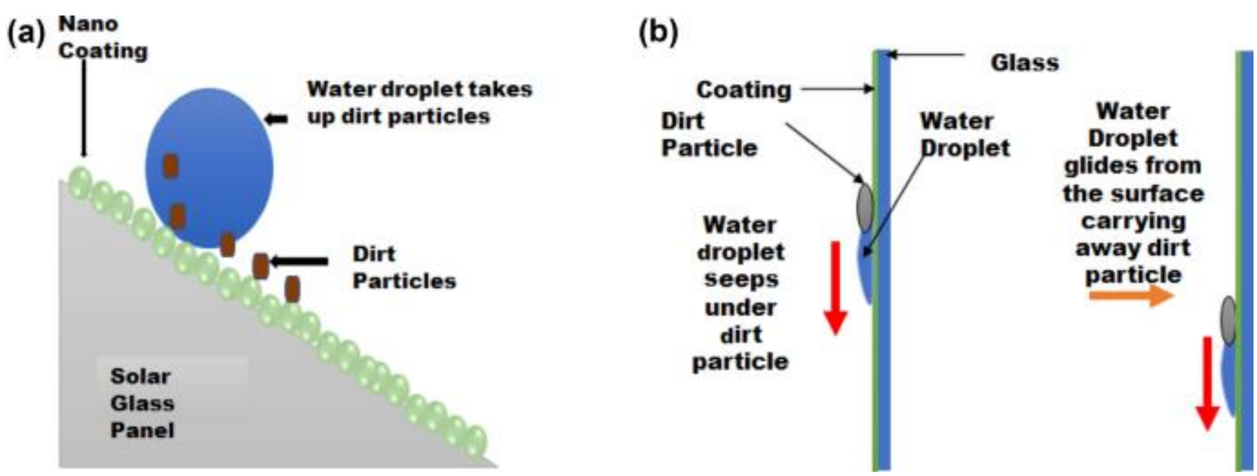


Figure 6 The behavior of water droplet on Wenzel Model and CB model.(Syafiq et al., 2018)Nanostructured Surfaces:

Nanostructured surfaces utilize advanced materials science to prevent dust and dirt from adhering to solar panels. These surfaces often incorporate nano-coatings that create super-hydrophobic properties, significantly reducing the need for manual cleaning and maintenance.

NEI Corporation: NEI Corporation specializes in nano-coatings that create super-hydrophobic surfaces, preventing dust and dirt from sticking to solar panels. This technology can dramatically reduce maintenance efforts and improve the efficiency of solar panels by maintaining clean surfaces.



Nanopool GmbH: Nanopool GmbH develops liquid glass coatings that form a thin, transparent layer over solar panels. This coating provides protection against dirt and weather elements, ensuring that solar panels remain clean and efficient.

Similar Works

In recent years, the development of advanced technologies for solar panels has significantly enhanced their efficiency, reduced maintenance costs, and improved overall performance. Two major innovations in this domain are self-cleaning coatings and sun-tracking systems. This literature review explores these technologies and their integration into solar panel systems, highlighting key advancements and industry applications.

Sun-Tracking Systems

Sun-tracking systems are designed to optimize the angle of solar panels throughout the day, ensuring maximum exposure to sunlight. These systems can significantly enhance the energy capture of solar panels, making them more efficient and productive.

Single-Axis Trackers:

Single-axis trackers follow the sun's path from east to west, adjusting the angle of solar panels to optimize energy capture throughout the day.

NEXTracker: NEXTracker's single-axis trackers, such as the NX Horizon system, are known for their efficiency and reliability in large-scale solar farms. These trackers optimize the angle of solar panels, enhancing energy capture and overall system performance.

Array Technologies: Array Technologies offers robust and efficient single-axis solar tracking systems like the DuraTrack HZ v3. These systems maximize energy output while minimizing operational costs, making them ideal for large-scale solar installations.

Dual-Axis Trackers:

Dual-axis trackers adjust solar panels along both horizontal and vertical axes, ensuring optimal solar exposure throughout the day and maximizing energy capture.

Soltec: Soltec's SF7 Bifacial tracker is a dual-axis tracking system that adjusts solar panels along both axes. This system is particularly beneficial for regions with high solar irradiance, as it ensures optimal alignment with the sun throughout the day.

SunPower: SunPower's dual-axis tracking systems, such as the Oasis platform, offer precise solar tracking capabilities. These systems maintain optimal alignment with the sun, maximizing energy production and enhancing the overall efficiency of solar panels.

Integrated Solutions

Some solar panel manufacturers integrate both self-cleaning coatings and sun-tracking capabilities into their products, offering comprehensive solutions that enhance solar panel efficiency and reduce maintenance requirements.

SunPower's Maxeon® Technology: SunPower integrates advanced solar cells with built-in microinverters and smart energy software. These systems may include options for sun-tracking and self-cleaning features, providing a holistic approach to maximizing solar panel performance.

First Solar: First Solar is known for its thin-film solar modules, which incorporate advanced material technology and design features. These modules can include compatibility with sun-tracking systems and self-cleaning enhancements, ensuring high efficiency and low maintenance.

The integration of self-cleaning coatings and sun-tracking systems represents a significant advancement in solar panel technology. These innovations enhance the efficiency, reduce maintenance costs, and improve the overall performance of solar energy systems. As research and development continue, we can expect further advancements and broader availability of such integrated technologies in the solar energy market. By adopting these technologies, the solar industry can achieve higher.

Methodology

The process by which this project approached generating viable concepts follows the standard methods used in conventional engineering. That is starting with needs identification - essentially outlining the properties that the device must possess to be inherently considered in the product design process. Next comes the concept generation stage, which is the brainstorming phase that strives to output as many viable ideas as possible to be able to evaluate and choose from and adapt to the final stage, prototyping.

Needs Identification

This stage ultimately results in a statement that contains all the desired attributes and properties that the product shall possess. This statement is called the Product Design Specification (PDS). It forms as a guide to the design process and narrows down the scope of the project to an attainable level. The following subsections outline the PDS statements set for this project's product.

Functionality

1. The product should be able to rotate about two axes to follow the sun.
2. The product should be able to wipe the solar panel clean automatically.
3. The product should be able to generate electricity more efficiently.
4. The product should allow for a variety of solar panel sizes.

Material

1. The product core should be made of durable material that will not buckle under heavier solar panel weight or external forces.
2. The product can use lighter material for non-stress bearing parts of the model.

Robustness

1. The product adopts a geometrically stable shape that will not topple easily.
2. The solar panel position should not be affected by external forces such as wind, stray animals (birds, squirrels, etc..)
3. The solar panel can be locked at one position for transportation.

Sustainability

1. The product shall use recycled material such as: recycled mdf wood, repurposed pvc pipe, recycled plastic sheets and 3d printed parts.
2. The product should be fabricated in a way that promotes reusing after the end of its lifespan.
3. The product's components can be recycled again to close the product life-cycle loop and remain sustainable.

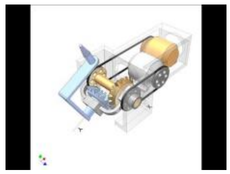
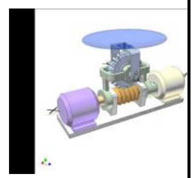
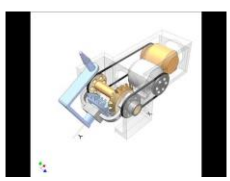
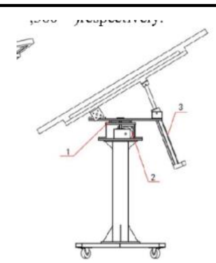
Ease of Maintenance

1. The product should have easy access to the electrical compartment for troubleshooting purposes.
2. The product should be easy to disassemble and reassemble.
3. The product's replacement parts should be easy to source and/or repair to lengthen the product's life
4. The product should be able to run autonomously with minimal to no user maintenance.

Concept Generation

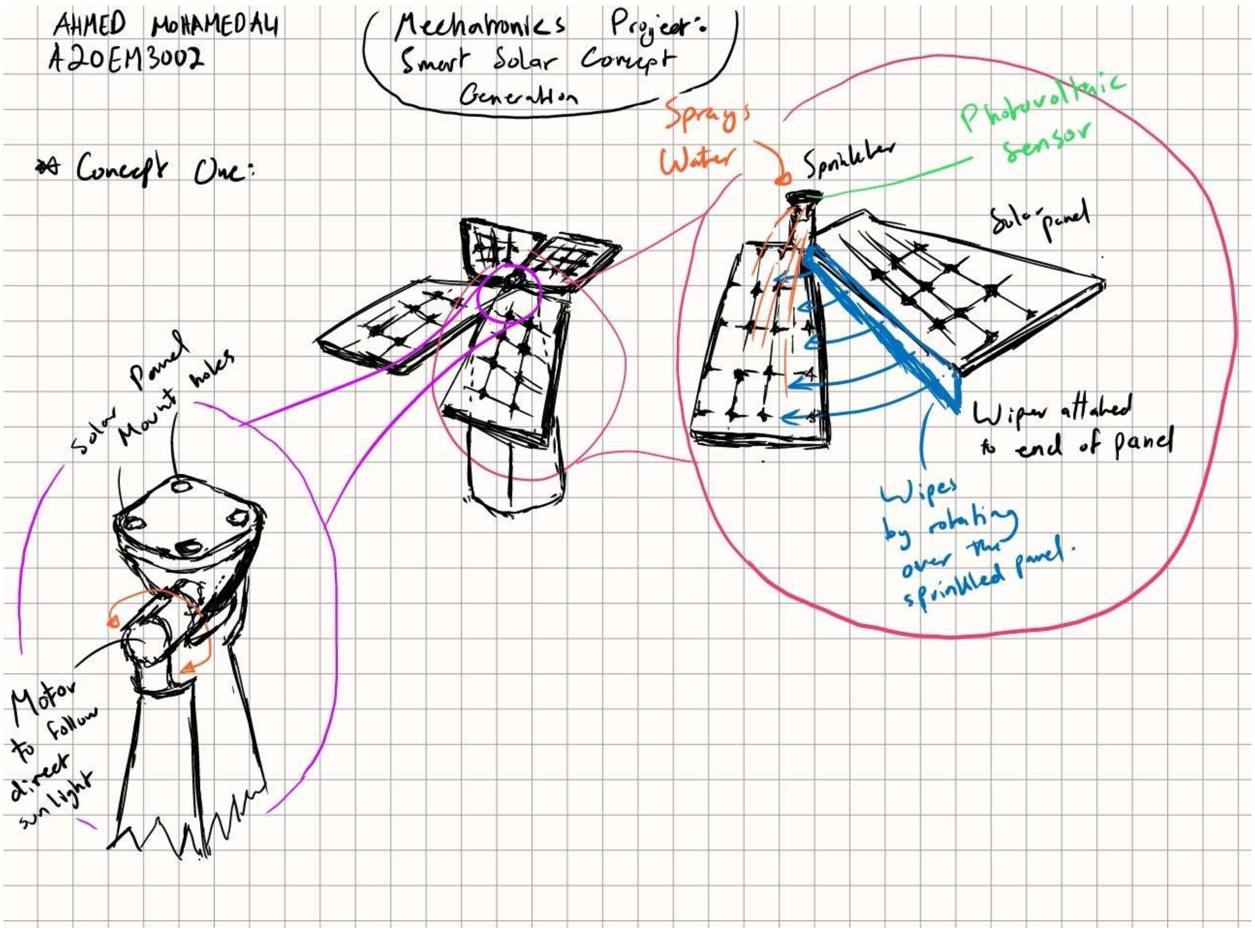
A morphological chart was constructed for each function of the solar panel in order to visualize the design decisions of each generated concept path.

Morphological Chart

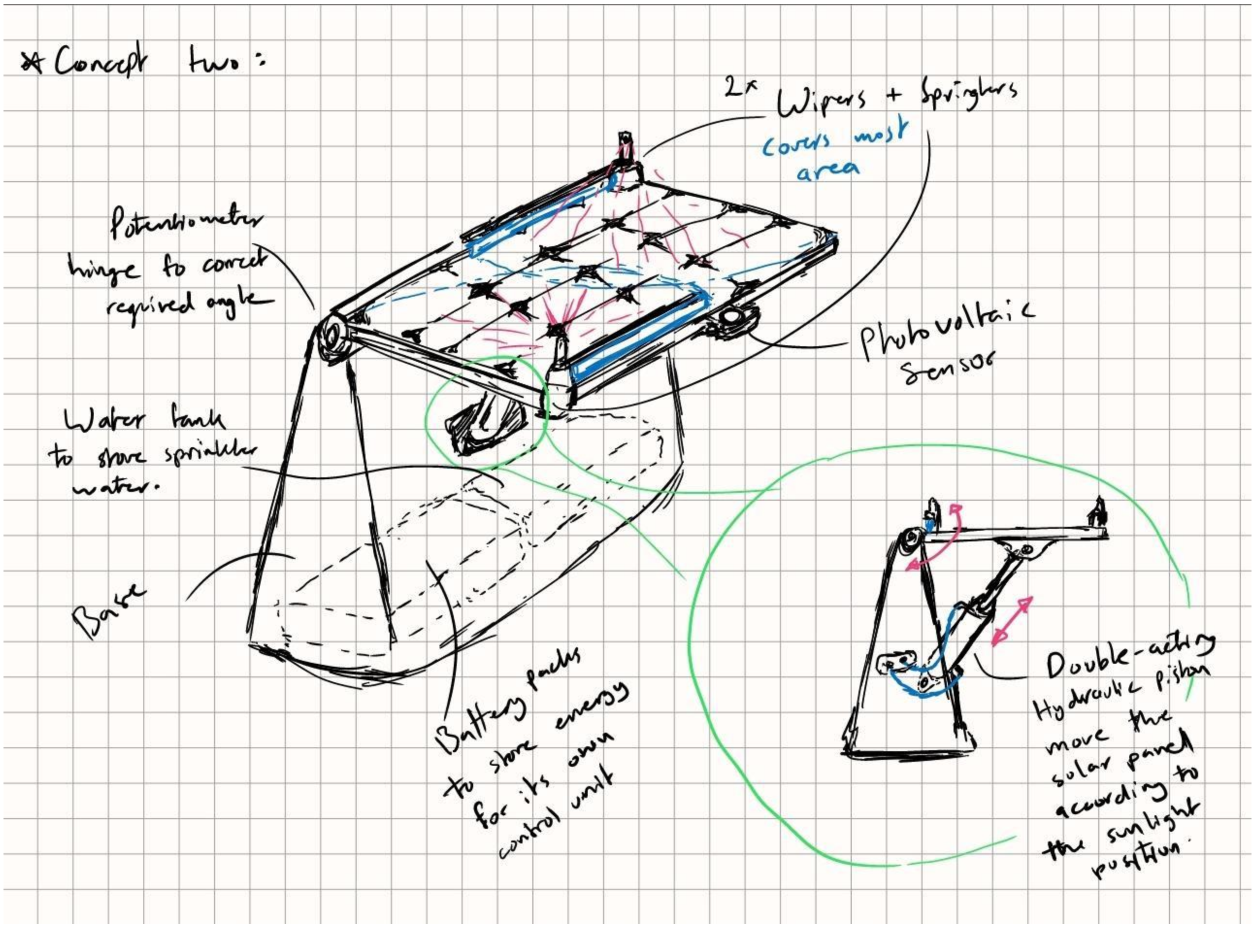
Function/Option	Option 1	Option 2	Option 3	Option 4
Axis 1 Rotation	 Bevel Gear	 Worm & Gear	 Spur Gear	 Slew Drive Gear
Axis 1 Actuator	 Servo Motor	 DC Motor	 Stepper Motor	
Axis 2 Rotation	 Bevel Gear	Direct Drive	 Tilting	 Spur Gear
Axis 2 Actuator	 Servo Motor	 DC Motor	 Linear Actuator	 Stepper Motor

Wiper Mechanism	Dual Arm - Car Windshield like	Single Arm (90 degrees)	Single Arm (180 degrees)	Linear Sliding Arm
Wiping Actuator	Stepper Motor	DC Motor	Linear Actuator	Servo Motor

Concept One

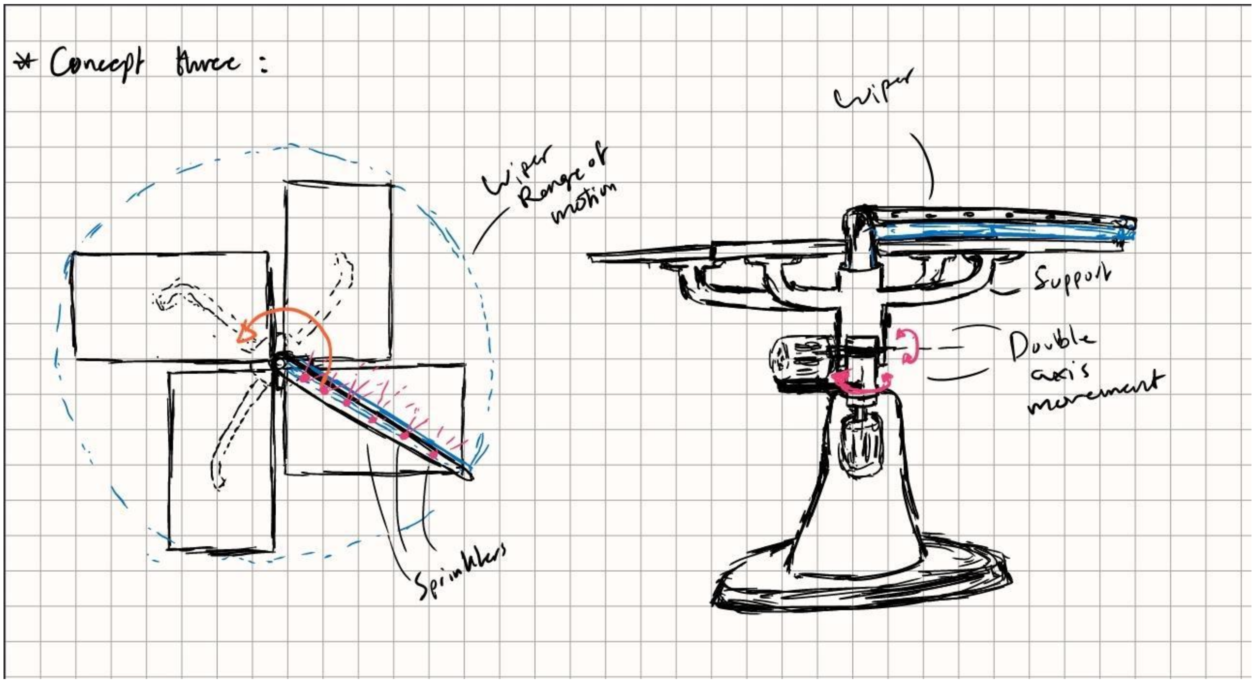


Concept Two

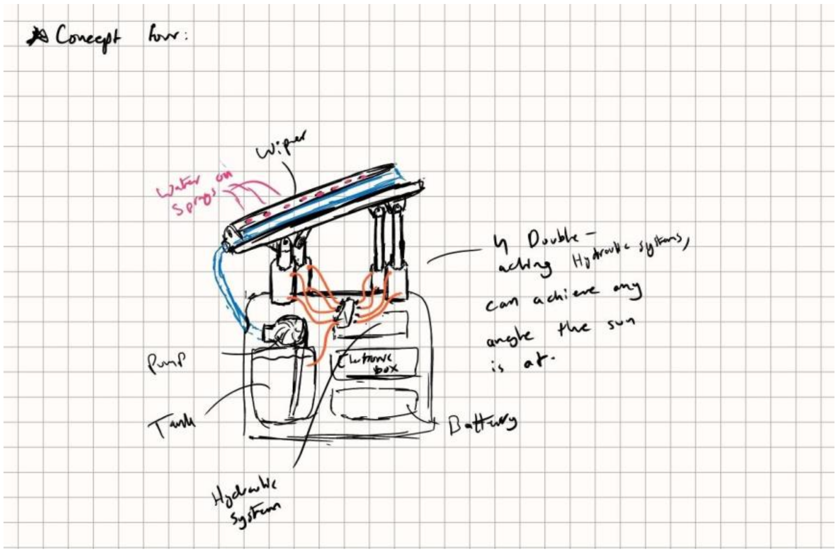


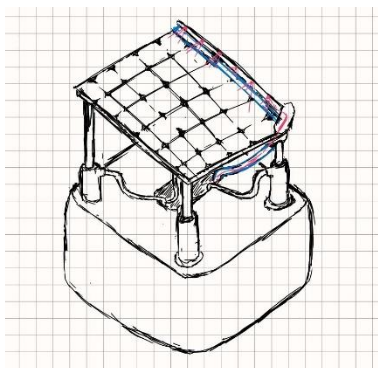
Concept two :
2x Wipers + Sprinklers
covers most area
Potentiometer hinge to correct required angle
Photovoltaic Sensor
Water tank to store sprinkler water.
Base
Battery packs to store energy for its own control unit
Double-acting Hydraulic piston move the solar panel according to the sunlight position.

Concept Three



Concept Four

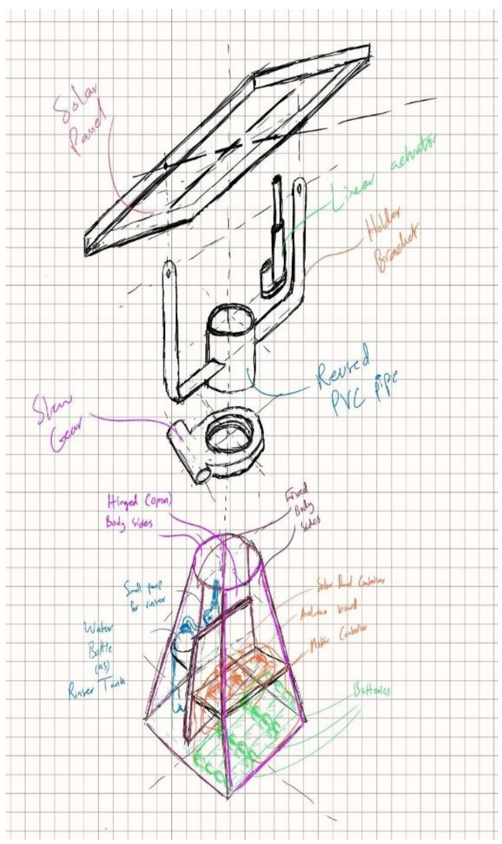




There were a plethora of routes that were viable to achieve the dual axis motion of the solar panel. However, by the aid of the PDS, it was inevitable to eliminate most of the generated concepts due to their lack of a specific property that is crucial for the sturdiness and rigidity of the product: the self-locking feature of the actuating mechanism. Therefore, this criteria filters out most of the options and leaves two types of axis rotation driving mechanisms: the worm drive or slew gear drive and the tilting motion by a linear actuator. Considering none of the aforementioned concepts generated satisfied the criteria, the final concept had adopted the best aspects from each of the concepts. For instance, the linear actuator was considered from the second concept and the shape of the body was taken from concept three.

Moreover, the wiping mechanism used to clean the solar panel included 4 options. Following the elimination approach, the options are brainstormed to evaluate its viability considering its performance, reliability, and ease of implementation. The linear sliding arm would require a belt and DC or stepper motor to drive the linear motion which, when brainstormed, would be hard to implement reliably. A linear actuator is not considered due its bulky nature for this application. A single arm that moves either 90 or 180 degrees to wipe the solar panel was considered initially. However, it has fallen short of the required criteria due to its inefficient wiping coverage and infeasibility due to physical constraints (solar panel holder bracket is taking the space where a single 180 wiper would be installed). Finally, the car windshield inspired design is considered and found to inherit many of the reliability and performance characteristics. Despite its slight difficulty in implementation, it has proven effective once done.

The following figure shows a visualized sketch of the generated concept of the sun tracking, self-cleaning solar panel in an exploded view.



Components

Solar Panel

Following the selection of the final concept, the components of the prototype were chosen. In this case, the following primary components were required:

- Motor
- Linear Actuator
- Stepper Motor
- Motor Drivers
- Microcontroller
- Power Source
- Solar Panel

The main concern with all the components was regarding their ability to handle the weight of a commercial solar panel with reference to the movement required.. The prototype covered two axes of movement, namely: Tilting and Rotation. Hence, motors capable of supporting the torque required as well as the force needed to tilt and rotate the panel were crucial.

As the limiting factor concerning all component selection was the solar panel itself, a full size commercial solar panel was chosen to embody realistic conditions in the field. The solar panel is as illustrated in the figure below.

Figure 7 Commercial Solar Panel

As can be seen, the panel comes with a commercial night light with a battery that can be charged through the panel. This is crucial to test the output of the panel. Furthermore, once the panel was obtained, detailed information was recorded as tabulated below.

Table: Solar Panel Details

Parameter	Value
Length	350 mm
Width	230 mm
Thickness	10 mm
Mass	800 g
Power Rating	10 W

<u>DC Motors and Actuators</u>

The next step in component selection is the motor. To accurately select the motor, we require the torque and the power. In this case where the primary function of the motor is to ensure rotation, torque is the biggest factor as the panel rotation does not overly focus on speed. In which case, a simple formula for the mass moment of inertia for a rectangular plate can be used to determine the resistance to rotation for a rectangular body.

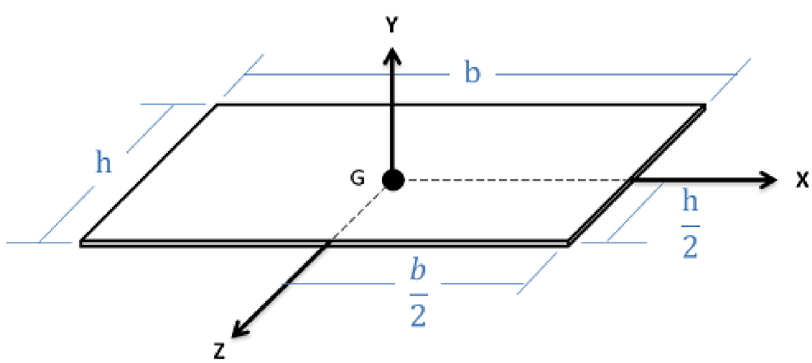


Figure 8 Rectangular moment of Inertia.

In our case the rotation required is in the y axis. Hence, Iyy needs to be determined through the formula below.

$$I_{yy} = (1/12) * M * (h^2 + b^2)$$

Where M corresponds to the mass of the solar panel (0.8 Kg), h corresponds to 230 mm, and b corresponds to 350 mm. Hence, the mass moment of inertia is calculated.

$$Iyy = 0.011693 \; Kg.m^2$$

This value can further be used in the formula relating torque and angular acceleration in the equation below.

$$Torque = Iyy \; * \alpha$$

Where alpha corresponds to angular acceleration. Assuming a simple angular acceleration of 1 rad/s^2, the torque can be calculated. In this case, the torque required is calculated to be (0.011693 Nm) which corresponds to (0.11923 Kgf .Cm). Essentially, the motor must be able to provide 0.11923 Kg of force one centimeter from the center of its rotating shaft to rotate the panel on its own axis. Hence, with this parameter an appropriate motor can be selected.

The type of motor is chosen first, as the application required rotation without much precision; a DC motor would fulfill all requirements, while being easy to control.

Figure 9 RoboTronik Custom Motor

Following the conservative torque estimate, the custom RoboTronik motor is chosen for its desired torque factor at a reasonable price. In addition, it is necessary to calculate the force required for a linear actuator to effectively tilt the panel. This can also be estimated using the mass moment of inertia and torque relation. Firstly, the formula for the mass moment of inertia about its Z axis is required, referring to the figure shown.

$$Izz = (1/12)\,mb^2$$

Where m = 0.8 Kg and b = 0.35m, hence Izz is calculated to be:

$Izz = 8.167x10^{-3}\ Kg.m^2$

Utilizing the equation relating torque and mass moment of inertia as previously shown.

$$Torque = Izz * \alpha$$

Assuming angular acceleration to be 1 rad/s^2 for simplicity, the torque can be calculated:

$$Torque = 0.008167\ Nm$$

As the distance from the center of the panel to the tilting edge is half of its height (0.175m), naturally the force required to produce the torque can be estimated. In this case, the force is calculated to be a minimum of 0.05 N. Hence, any linear actuator capable of outputting 0.05 N of vertical thrust will be able to tilt the panel effectively.

Figure 10 Aluminium Linear Actuator

Table: Linear Actuator Details

Parameter	Value
Stroke (mm)	50
Force (N)	150
Voltage (V)	12
Current (A)	2.0

The table above tabulates all the data related to the linear actuator. Observing the force rating, the aluminum actuator is able to easily tilt the panel without any difficulty.

Lastly, for the wiping mechanism the stepper motor 28byj-48 was used - The stepper motor allows precise motion at a low power usage and can easily be interfaced with the arduino.

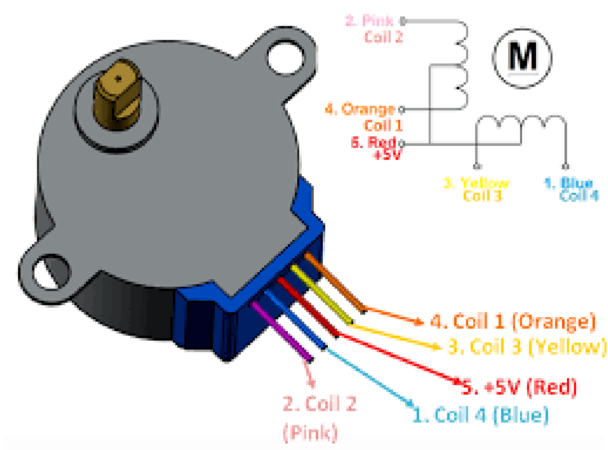


Figure 11 Stepper Motor

Motor Drivers

Analyzing both the DC Motor and the Linear Actuator selected, they have a common voltage rating of 12 V. Hence, a motor driver capable of that voltage rating is required. However, the linear actuator also requires a current of 2 A to function. As such, a motor driver capable of withstanding that current is required. This high current requirement rules out various common drivers, however the L298N H-Bridge driver is the best fit for both DC Motor and Linear Actuator as it allows two DC motors to be controlled and can withstand (2 A) active current.

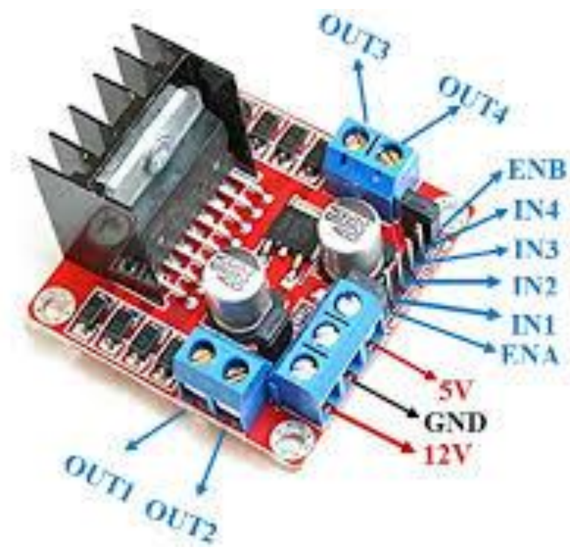


Figure 12 L298N Motor Driver Module

In contrast, the (4) pin stepper motor requires a different standard motor driver made specifically for stepper configuration. The ULN2003 motor driver allows complete control of the stepper motor with the arduino. Illustrated below, it has (4) input pins and (4) output pins to the arduino, and two separate pins for voltage and ground.

Figure 13 ULN2003 Stepper Driver

Sensor Selection

Following the concept generated, only one type of sensor will be used for this project. Two LDR's (Light Dependent Resistors) that will be mounted on each end of the solar panel to detect the difference in intensity of light from one side to the other. However, using an analog sensor requires various signal conditioning and filtering circuits. Hence, to simplify the process, a premade LDR module was used that supported three pins: VCC, GND and Digital Output. The LDR modules would be directly wired to the arduino's digital pins and simply detect the presence of light. However, the onboard potentiometer could be used to tune the specific intensity of light required.

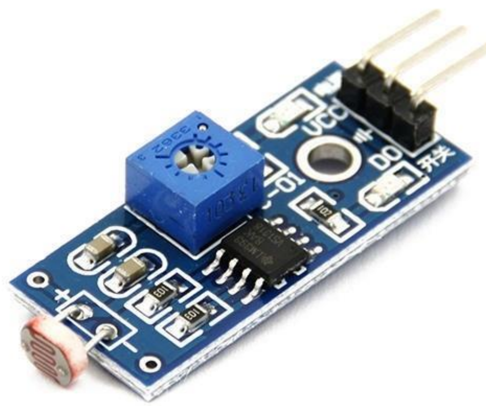


Figure 14 LDR Module Arduino

Circuit Diagram

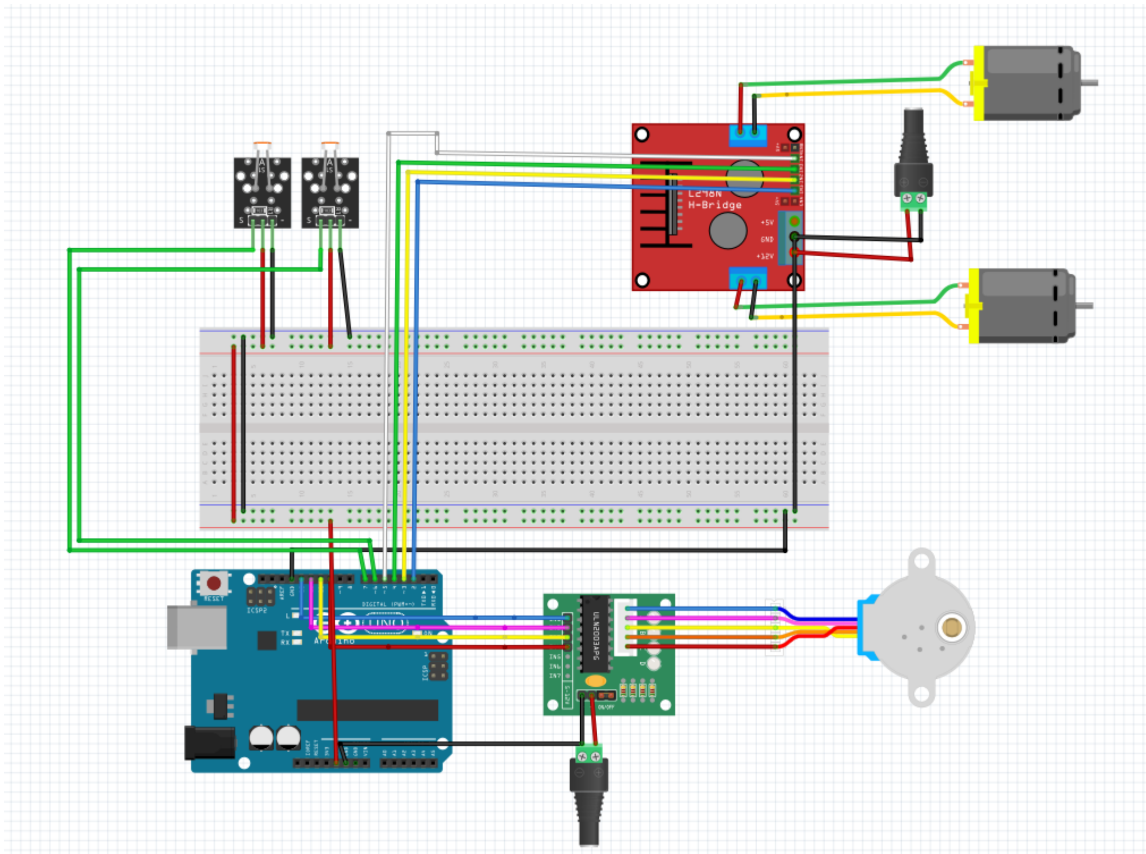


Figure 15 Circuit Diagram (BreadBoard)

Once all the components have been selected, the wiring would be as illustrated in the figure above. The key to ensuring a safe wiring setup is to wire a common ground between all motor drivers and the arduino- This would prevent surges in voltage as motors activate and shutdown. Without such a tweak the arduino could be exposed to residual voltages built up in the circuit due to extensive use of the motors, but a common ground would ensure there is never a voltage difference for any surges to occur.

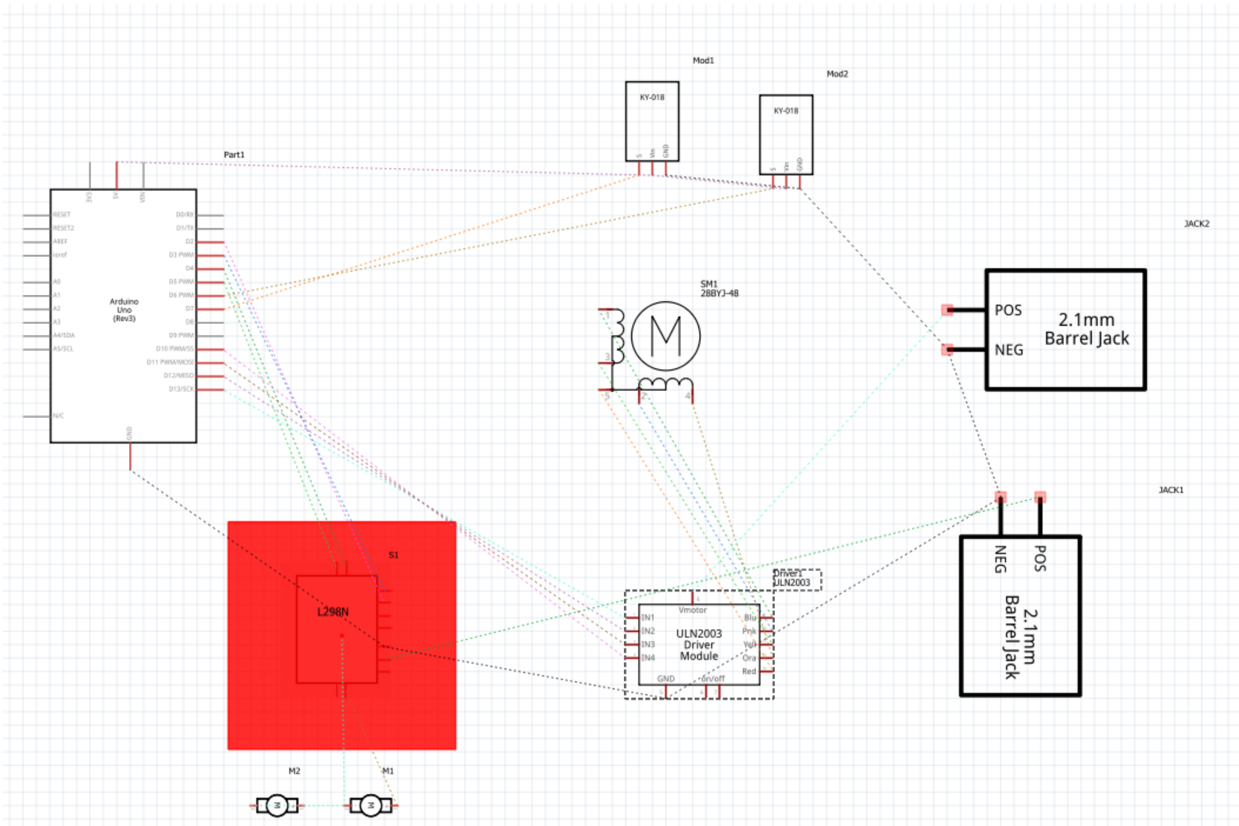


Figure 16 Writing Diagram (Schematic)

Wiring Steps

As illustrated in the wiring diagram, firstly both the DC motor and the Linear Actuator Motor are connected to output 1, 2, 3 and 4 of the L298N motor driver. This is followed by connecting the input pins of the L298N to the arduino's digital pins. Followed by connecting the voltage pin to the dc plug, as we all as connecting the ground pin of the arduino and the motor driver to the ground of the power supply.

Hence, the next wiring step is to connect the stepper motor to the ULN2003 driver. This connection is followed by connecting the four directional pins of the stepper to four digital pin outlets on the arduino board. Hence, finally connect the voltage pin on the ULN2003 to an external power source, and ensure command ground with the arduino.

Finally, wire the sensors to a breadboard and supply (5) volt power and ground through the arduino. Wire the digital output puns to two digital pins on the arduino. This concludes the wiring instructions. The final wiring diagram is as illustrated in the circuit diagram figure above.

3D Modeling

The use of a slew gear for this application was found to be rarely done in the scale of the prototype as this type of drive mechanism is often used in heavy duty, high torque load, and precision rotation applications. Hence, outsourcing this component was not an option. Rather it should be designed to specifically suit the project's use case.

A 3D model with the appropriate dimensions was designed using SolidWorks - a CAD software, to be 3D printed. The gear was designed with a slot that allows a 60mm diameter PVC pipe to fit perfectly into. As shown in the concept sketch figure in the concept generation section, this PVC pipe is made to hold the solar panel bracket.

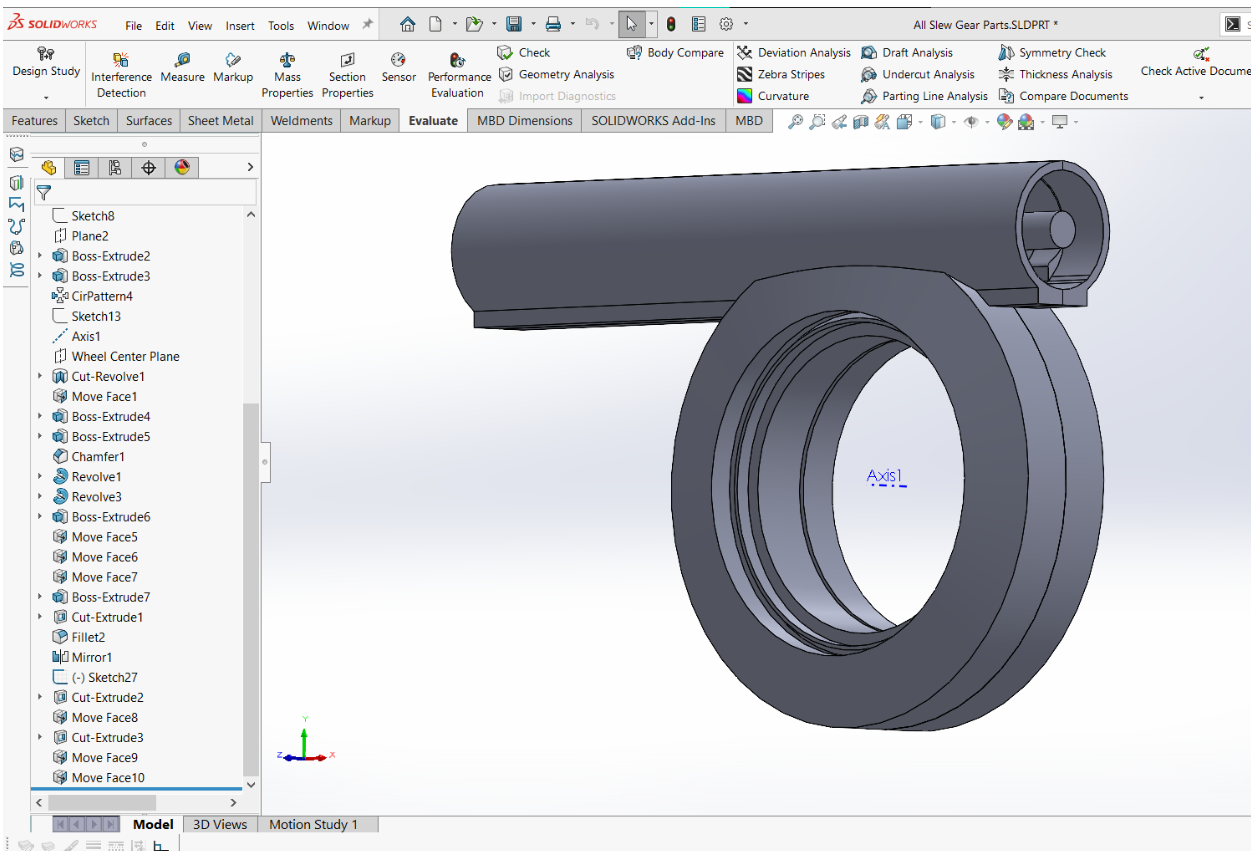


Figure 17 Modeled Slew Drive Gear Assembly.

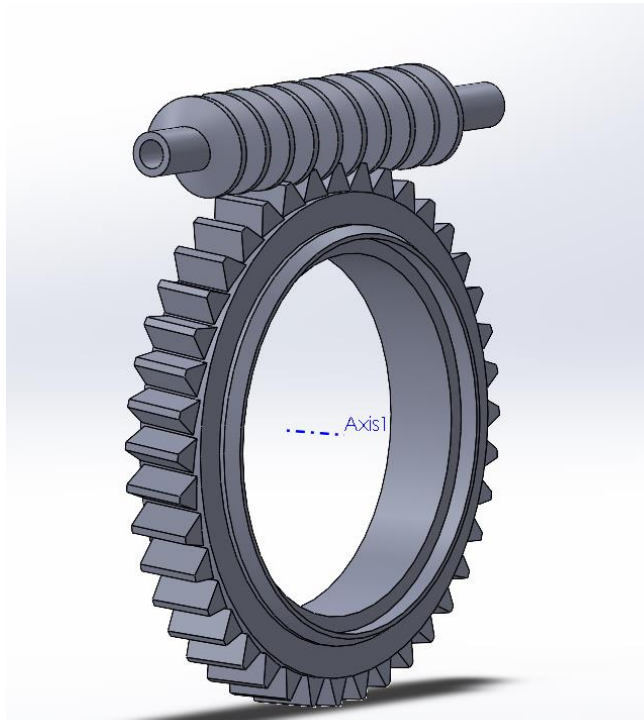


Figure 18 Worm and Gear Mesh.

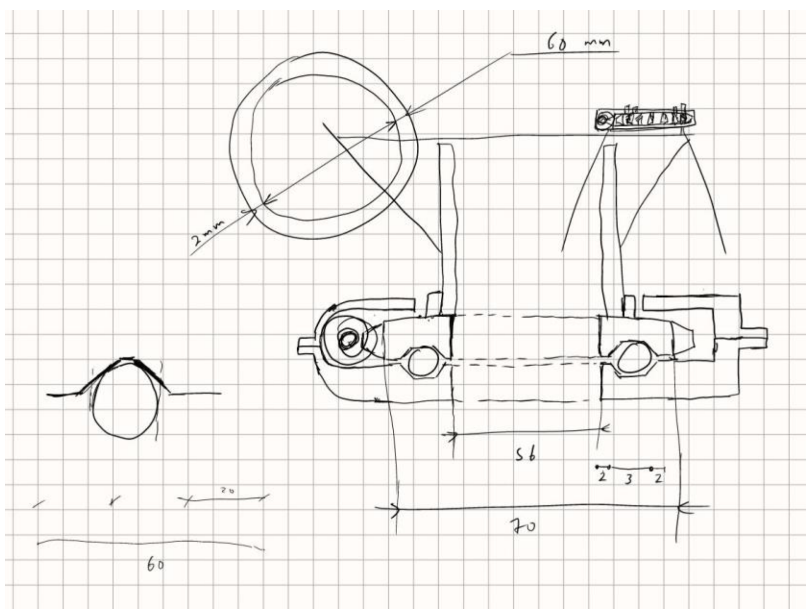


Figure 19 Slew Gear design calculations and modeling sketches.

The core of the product was made from recycled wood. The following figure shows the dimension sketch used in communication between the project team's members.

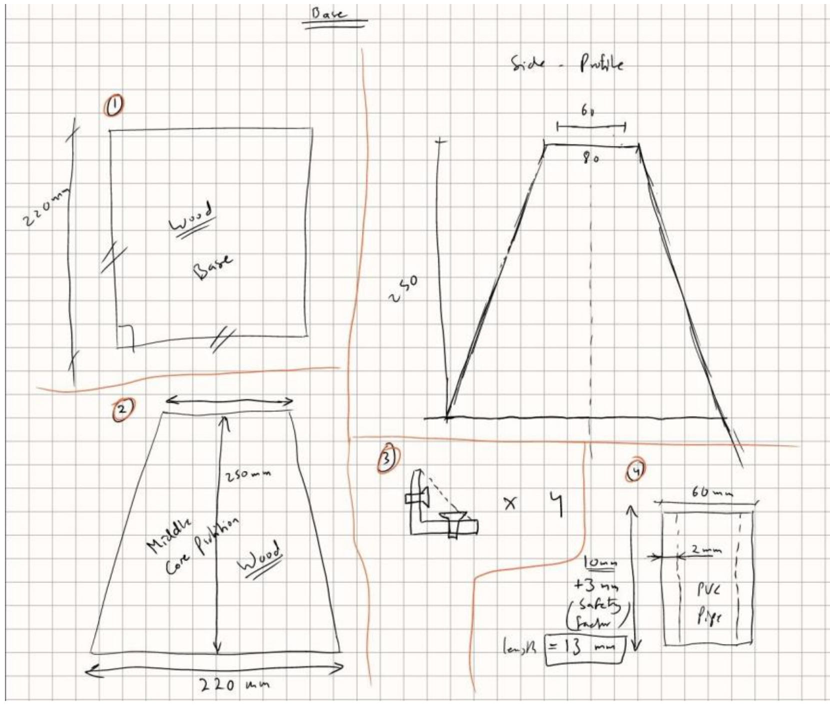
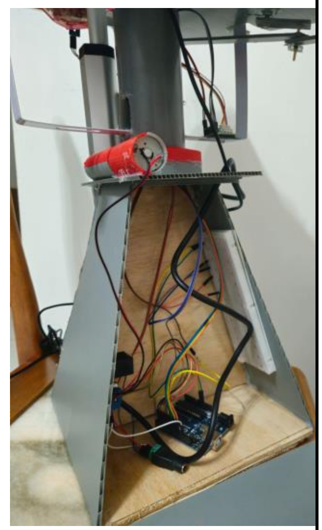
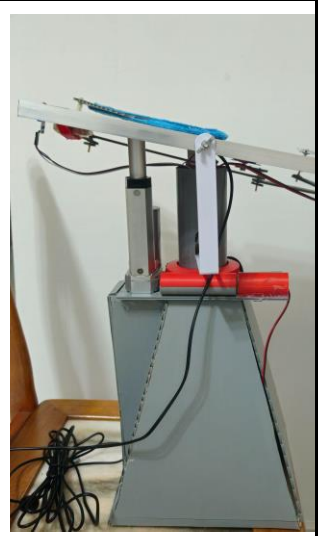


Figure 20 Base core structure modeling.

Prototype

The final prototype follows most of the design features of the final concept. The following figures shall present the resulting model.

 Front Isometric View	 Back Isometric View	 Open Electronics Compartment
 Front View	 Right View	 Left View

 Back View	 Top View	 Electronics Compartment Opening Tab
 Slew Gear	 Wiper Mechanism	[Blank Slot]

Table: Prototype model showcase pictures.

<u>Design Features</u>

- The hollow pvc pipe and slew gear are made to allow for easy cable management through them and into the electronics compartment.
- The electronics compartment can open up for ease of access for troubleshooting purposes.
- A weight is attached to the solar panel to make sure it tilts as intended when the linear actuator retracts. It must be noted that the linear actuator shaft cannot be stuck to the solar panel as that would not allow it to spin.
- The LDR sensors are placed at the edge of the solar panel; away from the range of motion of the wiper arms.

- The stepper motor controller module is mounted on the solar panel holder bracket to be closer and avoid any tugging of the cables while in motion.
- The wiper arms move 90 degrees to cover most of the solar panel cells area (ignoring the non-functional white area).
- The wiper linkages operate beneath the solar panel to avoid any obstruction while in motion.
- The side of the base where the linear actuator is mounted is reinforced with plastic sheets secured in a vertical orientation to enable higher load capacity on the slew gear platform.

Challenges Faced & Design Amendments

Upon moving on to the fabrication process, it was quickly realized that some of the functions are not feasible to be included in the design. For instance, the water spraying function was one that was omitted due to risks of damage of the electronic components in case of any leakage, which would be fatal for the project. In addition, the linear actuator placement was changed due to it being heavy and bulky in person. This meant that it could not be mounted on the solar panel holder bracket since it would result in severe imbalance causing it to topple over; which is detrimental to its stability. Therefore, a design decision was made to mount the linear actuator beside the slew gear; which means it would be stationary. Subsequently, this resulted in a slightly smaller range of motion of the solar panel's rotation around the (vertical) z-axis.

Programming

The code provided in the results section has been developed to manage a solar panel moving structure with the feature of auto cleaning. This system will use two DC motors for rotation and the other for actuation, a stepper motor for wiping, and two light dependent resistors. The code begins by including the necessary Stepper library and defining the pins connected to the LDR modules and motors. The stepper motor is initialized with the number of steps per revolution and the pins it is connected to. A flag variable is also defined to manage the direction of the cleaning process.

The initialization of serial communication is also carried out during the setup function for debugging purposes while the pins connected to the LDRs and motors are declared as either input or output. Setting the speed of the stepper motor is also done. The main loop pulls out the value stored in LDRs to identify the presence of light on the left and right side of the solar panel. When the left LDR is on, the second DC motor that is coupled to the panel for rotation will shift the panel to the left before the first DC motor which is for the actuation or change in position of the panel will act. The same process happens for the right LDR if it senses the light.

When neither LDR of the corresponding sides have detected light, a message is displayed on the serial monitor. Once the light is detected and the panel moved from its position to another, the flag is set to 0 for cleaning the surfaces. The stepper motor then rotates a full cycle of 2038 steps, to initiate the wiping process of the motor. Following a lapse of 2 seconds, the flag is set to 1 which informs that cleaning is done.

This code greatly helps in tracking as well as the self cleaning mechanism of the solar panel, to ensure that the panel faces the sun all day and is clean at all times. These processes are delegated to the system, which eliminates maintenance activities as well as enhances the generation of energy.

Results

The final prototype constructed for the self-cleaning solar tracking panel was capable of motion in two axes for tracking the sun and had the ability to clean its photovoltaic surface using two alternative wipers as can be seen in the figure below.

Figure 21 Isometric View of Prototype

As can be seen in the figure above, there are two LDR's mounted on each side of the panel's length. When the intensity of light on one side is stronger, then the entire assembly tilts to allow the panel more exposure- Increasing energy generation. Furthermore, the actuator used inherently has a stop lock feature hence the motion can only be possible when the sensors are triggered and the panel will stay locked in its position otherwise- Ensuring accuracy and stability.

The panel also rotates on its axis when it detects light- Making the panel perpendicular to the light source. Overall, the final prototype is capable of all functionality and was successfully exhibited and tested.

Arduino Programming

```
#include <Stepper.h>
#define DO_PIN 7  // Arduino's pin connected to DO pin of the ldr module
#define DO_PIN2 6
#define motor_1 2
#define motor_2 3
#define motor_3 4
#define motor_4 5
const int stepsPerRevolution = 2038;
Stepper myStepper = Stepper(stepsPerRevolution, 8, 10, 9, 11);
int flag = -1;
void setup() {
  // initialize serial communication
  Serial.begin(115200);
  // initialize the Arduino's pin as an input
  pinMode(DO_PIN, INPUT);
  pinMode(DO_PIN2, INPUT);
  pinMode(motor_1, OUTPUT);
  pinMode(motor_2, OUTPUT);
  pinMode(motor_3, OUTPUT);
  pinMode(motor_4, OUTPUT);
  myStepper.setSpeed(10);
}

void loop() {
int ldr = digitalRead(DO_PIN);
int ldr2 = digitalRead(DO_PIN2);

  if (ldr == LOW) {
    Serial.println("The light is present at left side");
    // 0 means LOW and 1 means HIGH
    digitalWrite(motor_3, HIGH);
    digitalWrite(motor_4, LOW);
    delay(8000);
```

```
        digitalWrite(motor_1, LOW);
        digitalWrite(motor_2, HIGH);
        delay(900);
        digitalWrite(motor_2, LOW);
        flag = 0;
    }
    else if (ldr2 == LOW) {
        Serial.println("The light is present at Right side");
        digitalWrite(motor_3, LOW);
        digitalWrite(motor_4, HIGH);
        delay(8000);
        digitalWrite(motor_1, HIGH);
        digitalWrite(motor_2, LOW);
        delay(900);
        digitalWrite(motor_1, LOW);
        flag = 0;

    }

    else{
        Serial.println("The light is not detected");
    }
    if (flag == 0){
        myStepper.step(stepsPerRevolution);
        delay(2000);
        flag = 1;
    }
}
```

Discussion

Challenges Faced:

Figure 22 Challenges in Prototype

The project encountered several challenges. Sensor accuracy was a significant issue, as the sensors used were not highly accurate, affecting the efficiency of solar tracking. Limited availability of components also impacted the overall design and functionality. Environmental factors, such as dust and other conditions, posed challenges for maintaining the efficiency of the solar panels. Financial constraints restricted the choice of high-quality materials and components. Additionally, the setup process, particularly the wiring, was time-consuming and complex, leading to delays.

Resolutions

To address these challenges, several measures were taken. Sensor calibration was improved to enhance accuracy in solar tracking. Alternative components that were more readily available were sourced to meet design requirements. The prototype was adjusted to better withstand environmental factors, including improved shielding and coating. Budget-friendly solutions were implemented, such as using a strong flashlight to simulate sunlight for testing. Efforts were also made to streamline the setup process by organizing wiring more efficiently and creating a detailed setup guide.

Recommendations

For future projects, it is recommended to use advanced sensors with higher accuracy for better performance. Investing in high-quality components can significantly improve the efficiency and durability of the system. Implementing state-of-the-art self-cleaning coatings can further reduce maintenance efforts and improve efficiency. Comprehensive testing in various environmental conditions can provide better insights into the system's performance and areas for improvement. Developing efficient setup practices, such as using modular components and pre-assembled wiring harnesses, can reduce setup time and complexity. This streamlined section captures the essence of the challenges, resolutions, and recommendations without listing too many points.

Conclusion

Overall, the objectives of this project were to construct a fully operational self-cleaning solar tracking panel. Observing the results obtained, the objectives were achieved successfully. The final prototype was fully functional and was capable of achieving the desired precision in sun tracking through light intensity. Furthermore, the prototype successfully integrated linkages in wiping mechanisms to ensure alternating wipers kept its surface clean and dust free.

However, there were various challenges faced in this project primarily due to the lack of commercial parts available and the limited sensitivity of components on the market. The project was constructed through recycled materials and hence sacrificed a certain threshold of operational accuracy in lieu of cost efficiency. In conclusion, the project was successful in constructing a working prototype, but the final prototype is yet to be fully tested in dynamic environments and hence should be used with caution. More testing should be conducted, and development should be focused around ensuring precision and accuracy.

References

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Abhilash, B., & Panchal, A. K. (2016, February). Self-cleaning and tracking solar photovoltaic panel for improving efficiency. In *2016 2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB)* (pp. 1-4). IEEE.

Appendix

Arduino Code:

```
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#define DO_PIN 7  // Arduino's pin connected to DO pin of the ldr module
#define DO_PIN2 6
#define motor_1 2
#define motor_2 3
#define motor_3 4
#define motor_4 5
const int stepsPerRevolution = 2038;
Stepper myStepper = Stepper(stepsPerRevolution, 8, 10, 9, 11);
int flag = -1;
void setup() {
  // initialize serial communication
  Serial.begin(115200);
  // initialize the Arduino's pin as an input
  pinMode(DO_PIN, INPUT);
  pinMode(DO_PIN2, INPUT);
  pinMode(motor_1, OUTPUT);
  pinMode(motor_2, OUTPUT);
  pinMode(motor_3, OUTPUT);
  pinMode(motor_4, OUTPUT);
  myStepper.setSpeed(10);
}

void loop() {
int ldr = digitalRead(DO_PIN);
int ldr2 = digitalRead(DO_PIN2);

  if (ldr == LOW) {
    Serial.println("The light is present at left side");
    // 0 means LOW and 1 means HIGH
    digitalWrite(motor_3, HIGH);
    digitalWrite(motor_4, LOW);
    delay(8000);
    digitalWrite(motor_1, LOW);
    digitalWrite(motor_2, HIGH);
    delay(900);
    digitalWrite(motor_2, LOW);
    flag = 0;
```

```
  }
  else if (ldr2 == LOW) {
    Serial.println("The light is present at Right side");
    digitalWrite(motor_3, LOW);
    digitalWrite(motor_4, HIGH);
    delay(8000);
    digitalWrite(motor_1, HIGH);
    digitalWrite(motor_2, LOW);
    delay(900);
    digitalWrite(motor_1, LOW);
    flag = 0;

  }

  else{
    Serial.println("The light is not detected");
  }
  if (flag == 0){
    myStepper.step(stepsPerRevolution);
    delay(2000);
    flag = 1;
  }
}
```