Solar Panel Cleaner

Team #26

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Introduction

Problem

Solar panels are constantly exposed to environmental elements like dust, pollen, and even bird droppings, all of which can accumulate on the surface and block sunlight. Even partial shading or debris on the surface can reduce the panel's output power, especially if there is partial shading across individual cells due to a solar panel's properties. Manual cleaning of panels is labor-intensive and impractical for large arrays. In addition, improper cleaning can damage the delicate anti-reflective surface of solar panels, causing long-term performance degradation.

Solution

Our goal is to create an affordable, reliable, consistent, and adaptable solar panel cleaner to improve energy efficiency among solar panels on the roof of the ECEB. For demonstration purposes and proof of concept, we will demonstrate on a solar panel borrowed from ECE Power Facility indoors. We are designing a rail-based solar panel cleaner that have two degrees of motion: vertically and horizontally. The controller will sit at the top of the solar panel along a horizontal spanning rail to move the cleaner unit along the panel. The cleaner unit will be attached two rails spanning vertically to scale the cleaning unit up and down the panel. Both the controller unit and cleaner unit will be connected to a stepper motor, pulley system, and belt to guide them along the rails. The cleaning action is planned to have an interchangeable microfiber cloth, rotating brush, and cleaning solution dispenser.

Visual Aid

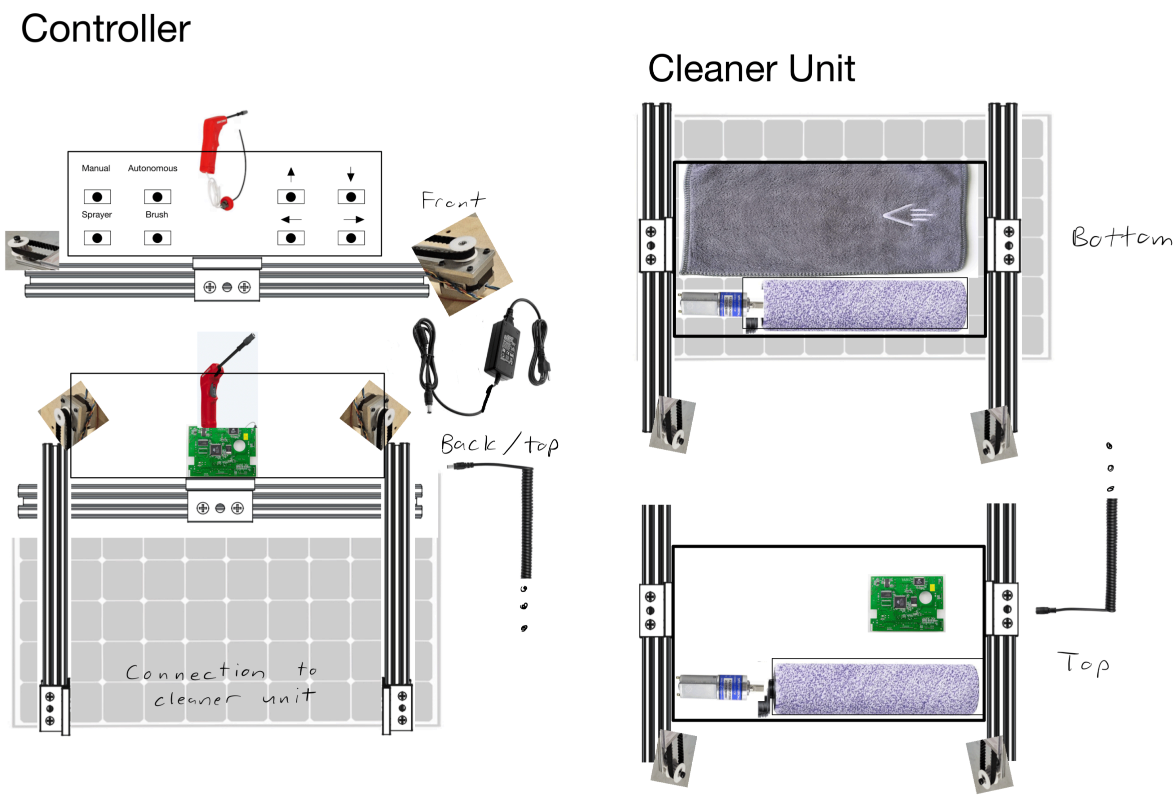

Figure 1: Visual diagram of a theorized controller and cleaner unit module

High-level requirements list

- Have the cleaning system implementation work for its entirety; the sprayer dispenses solution on the panel, the brush is able to spin on the cleaner unit, and the microfiber cloth picks up leftover debris
- Allow the user to enable between manual and autonomous modes for the cleaning unit to run on without needing to restart the cycle.
- Have the cleaner unit complete a full vertical sweep (top to bottom and back to top) in under 10 minutes, ensuring timely and efficient cleaning.

Design

Block Diagram

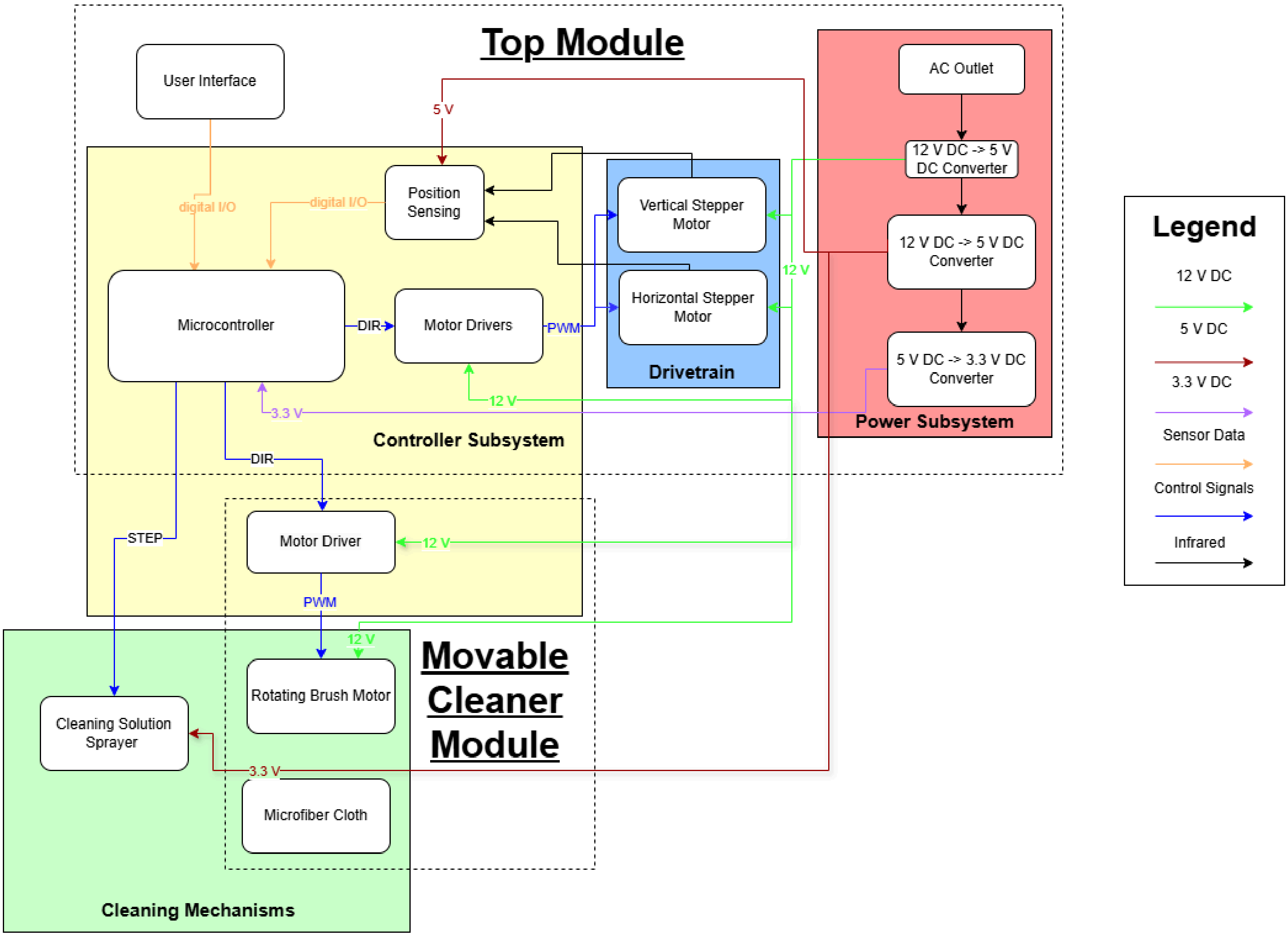

Figure 2: Block diagram of our solar panel cleaner

Subsystem Overview

Power Subsystem

The power subsystem is responsible for supplying power to our cleaner. It draws power from a 120V AC outlet, and then rectifies and converts it into three DC buses, with voltages of 12V, 5V, and 3.3V, respectively. These DC buses are then connected to other subsystems to power motors, sensors, the cleaning solution dispenser, and the microcontroller. The main components of this subsystem are: a 120-12V AC-DC converter, a 12-5V DC-DC converter, a 5-3.3V DC-DC converter, and their corresponding voltage regulators. Additionally, we might add fuses or other protective components for safety.

Controller Subsystem

The controller subsystem is responsible for receiving inputs from the user interface and position sensor and outputting control signals to control the drivetrain's motors, rotating brush motor, and cleaning solution sprayer.

Drivetrain

The drivetrain subsystem is mainly mechanical and is responsible for moving the cleaning module on the solar panel. The drivetrain subsystem consists of a horizontal rail, two vertical rails, and complementary motors, gears, pullets, and bands for their movements. The horizontal rail will be attached to the top of the solar panel, housing the controller subsystem. The two vertical rails are attached to the controller subsystem in parallel, one on each side. The cleaning module is then connected between these vertical rails. The complementary motors, gears, and bands will be able to move the cleaning module vertically along the rails, and the entire system horizontally along the top rail. These motors are controlled by the controller subsystem, and powered by the power subsystem.

Cleaning Mechanisms

The cleaning mechanisms subsystem is responsible for cleaning the solar panel. It consists of a rotating brush and its corresponding motor, a cleaning solution bottle and sprayer, a microfiber cloth, and the container that houses all these components that is attached to the vertical rails. The brush motor and solution sprayer are controlled by the controller subsystem, and powered by the power subsystem. The cleaning solution sprayer would spray the solution periodically to moisten the resilient stains, while the rotating brush rotates and brushes them off. The microfiber cloth will do the final round of cleaning, wiping off the remaining residue.

Subsystem Requirements

Power Subsystem

- AC wall power must be converted to 12 V DC, 5 V DC, and 3.3 V DC, all +/- 10%.
- The system must be able to handle at least 4 A of continuous current while remaining within +/- 10% voltage tolerance.
- If the subsystem were to fail, motors, sensors, and controllers would not be able to function as they are dependent on a voltage source to run.

Controller Subsystem

- The movement buttons cause the positioning motors to engage
- The sprayer button successfully causes the nozzle to activate on and off
- The brush button successfully causes the brush motor to engage and unengage
- The manual and autonomous buttons cause the internal logic to switch modes
- The microcontroller is able to read from the position sensors.
- The microcontroller in autonomous mode reacts to the position sensing and sends signals to the motor drivers and cleaning solution sprayer based on the position.
- If the subsystem were to fail, the entire system would lose its ability to function, with no motor control, sprayer, or brush control.

Drivetrain

- The STEP, DIR, and ENABLE signals from the microcontroller to the motor drivers to control the stepper motors attached to the pulley system.
- The position sensors need to provide real-time feedback on the ends of the rail to tell the controller when the cleaner unit is at the end of the rail and tell the drive train to stop.
- The system must complete a full vertical sweep (top to bottom and back to top) in under 10 minutes.
- The stepper motors must operate at a voltage of 12 V +/- 10% and draw no more than 2 A each.
- The pulley/belt system must be able to support and move the cleaning unit without slipping or excessive tension.
- If the system fails, the stepper motor may draw too much current and overheat, or not move at all.

Cleaning Mechanisms

- The sprayer activates and the spray is able to reach the entire vertical length of the panel.
- The brush motor activates and spins to with 10% of rated RPM when operated under no load.
- If the subsystem were to fail, dirt, debris, and other particles would remain on the panel, rendering our device rather useless.

Tolerance Analysis

One of the most crucial parts of our design is the cleaner unit moving up and down the solar panel to clean, accomplishing our desired task. We need to determine a rough estimate for amount of torque needed for our vertical motors that move our cleaner up and down the panel. We considered both the gravitational force acting on the sloped solar panel and the centrifugal forces generated by the spinning brush. We want to determine the operating speed of the brush, so we plotted different speeds vs expected torques to help us select motors for the brush (RPM focused) and pulley system (torque focused)

We had some estimated parameters found either by trigonometry, datasheets, or estimates. We estimated: the solar panel slope = 21°; mass of cleaning unit = 4 kg; brush radius = 0.05 m; moment of inertia for brush = 0.025 kg·m^2; and let the brush speed vary from 0 RPM to 1000 RPM. The torque due to gravity was found by $\tau_{gravity} = F \cdot r = m \cdot g \cdot sin(\theta) \cdot r$. The torque due to the centrifugal torque is a little different. Centrifugal force on a mass unit is $F_c = m \cdot r * \omega^2$ [2]. Thus, $\tau_{centrifugual} = F_c \cdot r = m \cdot r^2 * \omega^2$. With moment of inertia being $I = m \cdot r^2$ and $\tau = I \cdot \alpha$, and assuming steady state speed of the brush, we can simplify $\tau_{centrifugual} = I * \omega$. Using this, we can add the two torques for different speeds and calculate the total amount of torque demand vs speed.

From this analysis, we are able to select a desired speed for the brush, and choose the corresponding torque needed from the NEMA stepper motor.

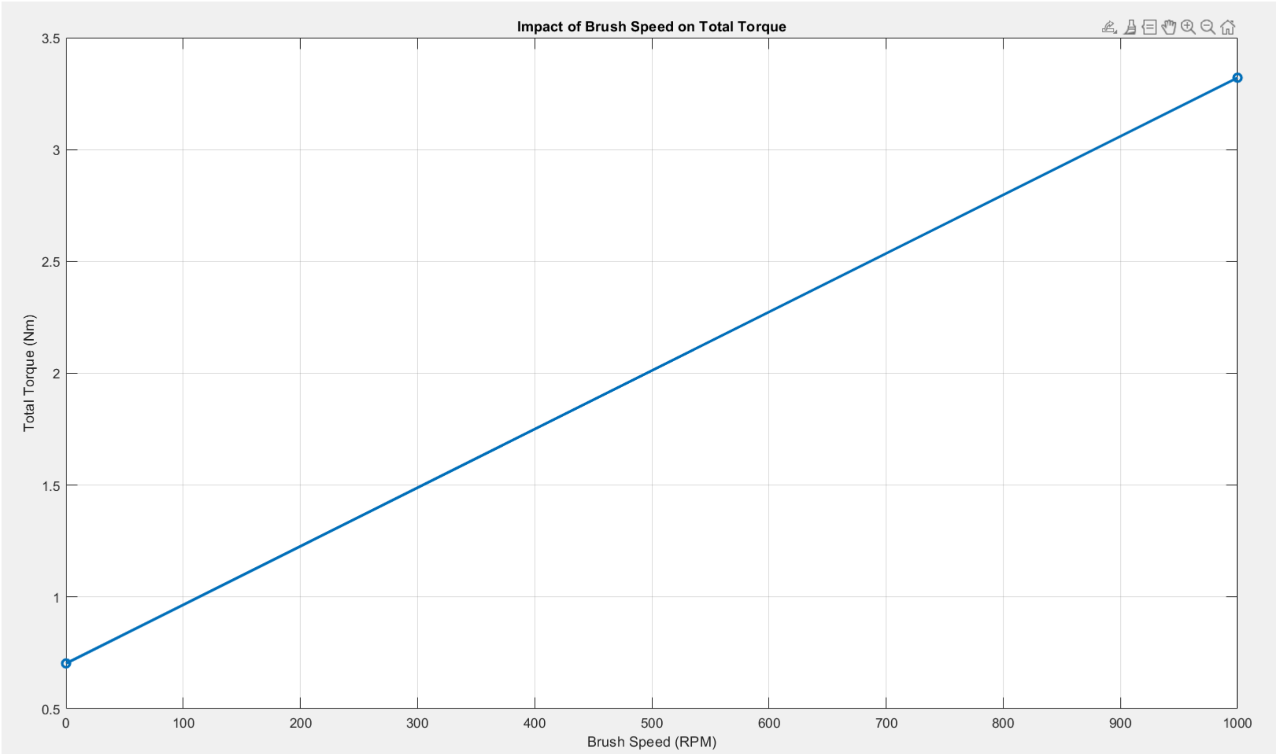

Figure 3: Estimated torque vs brush speed plot for cleaner unit module

Ethics and Safety

Ethics

We recognize the importance of addressing potential ethical and safety issues related to our Solar Panel Cleaner. To ensure that the work conducted is ethical and safe, we will closely follow the IEEE Code of Ethics [1].

Safety and Sustainability

Our top priority is the safety of our users, the solar panels, and the environment. Our goal is to design and assemble a cleaner that is safe to operate and gentle enough to avoid damaging the solar panels. We also plan to use eco-friendly cleaning solutions to minimize harm to the environment.

Equality

We aim to design an inclusive and accessible product that can accommodate a wide range of users. We intend to create an easy-to-use cleaner at a low cost, enabling users from various backgrounds to benefit from it. The rail system of the cleaner is also scalable, making it adaptable to different setups.

Honesty and Transparency

Throughout the process, we will uphold the highest standards of integrity. We will present our product honestly and in accordance with the IEEE Code of Ethics.

Safety

In our project, we plan to power our cleaner through an electrical outlet. However, this could pose a safety risk if the outlet or cable is exposed to moisture or rain. Additionally, most of the electrical components in our cleaner are sensitive to the surrounding environment. Therefore, it is crucial to design weather-proof enclosures for the device and to ensure that users store hazardous components safely before inclement weather occurs.

We also intend to transfer power from the control module to the cleaning module. If not installed properly, the transmission wire could become entangled in the pulley system or the cleaning module, potentially causing short circuits or creating a shock hazard. To minimize this risk, we should use high-visibility cables and install appropriate accessories to reduce the likelihood of the cables getting caught.

The pulley system poses another risk, as it could entangle objects such as hair or clothing. For safety, it is recommended to maintain a safe distance from the cleaner during its operation.

Furthermore, the operating environment may experience high temperatures due to solar radiation, which could lead to material or device failures in extreme cases. To address this, we plan to incorporate reflective materials into the cleaner’s surfaces to minimize heat absorption from solar exposure.

References

[1] “IEEE code of ethics,” IEEE, Jun-2020. [Online]. Available: https://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 10-Feb-2025].

[2] Wikipedia Contributors. “Centrifugal Force.” Wikipedia, Wikimedia Foundation, 17 Nov. 2019, en.wikipedia.org/wiki/Centrifugal_force.

Appendix

```
g = 9.81;
solarpanel_angle_deg = 21;
angle_rad = deg2rad(solarpanel_angle_deg);

% estimated paramaters, can be improved once model is built
mass_cleaner_unit = 4;
radius_brush = 0.05;
moment_of_inertia_brush = 0.025;
brush_speeds_rpm = [0, 1000];

torque_gravity = mass_cleaner_unit * g * sin(angle_rad) * radius_brush; % τ = force x r

total_torque = zeros(1, length(brush_speeds_rpm));
for i = 1:length(brush_speeds_rpm)
    speed_rpm = brush_speeds_rpm(i);
    speed_rad_per_sec = speed_rpm * 2 * pi / 60;

    torque_brush_centrifugual = moment_of_inertia_brush * speed_rad_per_sec; % τ = F*r = m*r^2*ω^2 = I*ω (assuming brush is spining at constant speed)

    total_torque(i) = torque_gravity + torque_brush_centrifugual;
end

figure;
plot(brush_speeds_rpm, total_torque, '-o', 'LineWidth', 2);
xlabel('Brush Speed (RPM)');
ylabel('Total Torque (Nm)');
title('Impact of Brush Speed on Total Torque');
grid on;
```

Figure 4: Associated code for finding estimated torque vs speed