Introduction

Renewable energy is becoming a predominant form of energy around the world, especially solar panels. This project began based on the new demand for residential solar panels. With the increasing demand of solar panels come the increasing demand for maintenance on them and this includes the cleaning of the panels. The panels get a buildup of dirt, pollen, leaves and anything the outside world can throw at them and this brings down their efficiency. The technology used now to clean the panels is manual labor with a brush and solution that takes a couple hours to perform. Within these hours, an entire system can be installed on a roof. Thus, our project came along, an autonomous non-destructive device that can clean solar panels.

Based on our customer needs that were given by our sponsor, the requirements for the device were then created. Beginning with the ability to clean the panel, our device must be able to clean the solar panels efficiently and to the customers satisfaction. Other requirements were the need for the device to be autonomous, a power source that will power the robot for as long as necessary to clean the panels, solution to clean the panel and support for the robot so it will stay on the panel as it cleans.

Below is the detailed description of how our team fulfilled the needs we were presented by our customer, beginning with a description of our final design. Then our robot is broken down into mechanical and electrical components then brought together to see how the whole robot will be able to perform its task.

Selected Concept

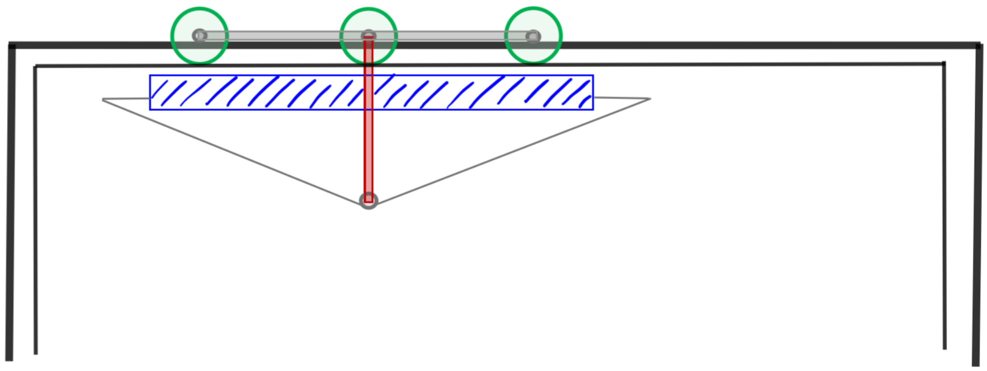

Figure 1

Figure 1 above shows the cylindrical brushes, similar to that of a long paint roller. This roller will have bristles on it and, in conjunction with the solution, will be utilized to loosen and clean off the material on the solar panels. Figure 1 also highlights the telescoping rod that will be used to traverse the brush system across the array. This telescoping rod will extend mechanically to reach the other edge of the panel. The idea is the brushes will turn continuously while a separate motor and gear system extends the telescoping rod, solution will be distributed at a constant rate at the head of the brush. The rod will extend to the edge of the panel (sensed using mechanical and electrical methods) and then retract back to its original position. When back to the fully retracted position there will be a portion of the panel along that column that is not completely cleaned due to the nature of a telescoping rod, there will always be a minimum that the rod can be retracted. In order to account for this minimum retraction distance the telescoping rod will be lifted above the panel so that the brush comes back at an angle to a fixed position allowing for the brush to reach the end of the rod despite this minimum retraction distance. Once the column is cleaned, and the brush has returned to its original position, a set of 3 V-Grooved caster wheels (2 being motor driven) attached to the rod, will turn. This will reposition the cleaning device to the next column to start the process again. Thus, emulating the same cleaning motion and process a human worker would do with a similar brush.

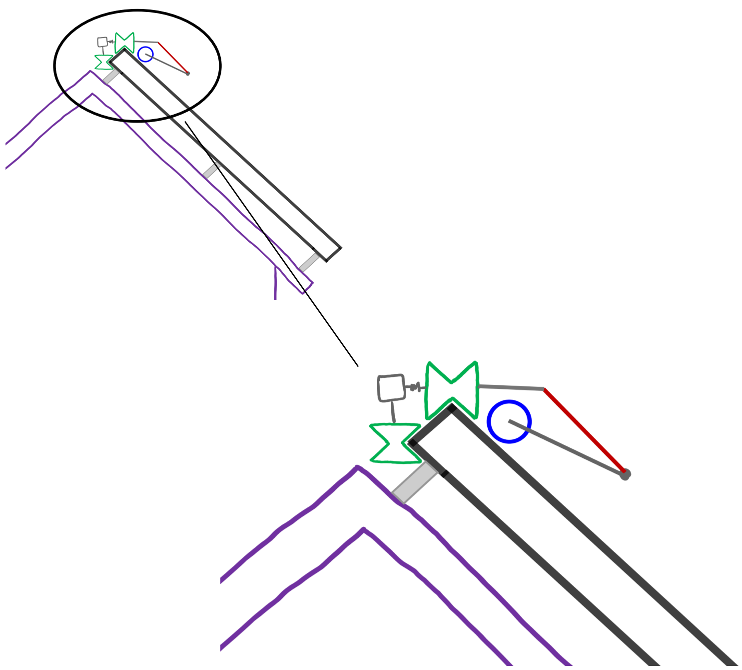

Figure 2

This side profile in figure 2 shows the backwards angle of the roller brush from a different perspective, showing how the rod will be raised above the panel allowing for the brush to go underneath and reach the topmost point of the panel. Also highlighted in the profile view of the design is a better view of the horizontal moving component that will be in three places along the top of the panel (to better distribute load and pressure). The v notched wheels are used in order to keep the system at the desired angle and allow for the structure to be held by all sides of the edge, increasing structural stability. The wheel on the front of the panel will be driven using a motor while the one on the bottom will roll in conjunction with the top wheel because it is not driven. Due to the small area to work with on the side of the panel the v-wheel on the bottom may have to be designed differently to allow for more space. The alternative design for this would be a fingered design that rides along the bottom of the panel for stability purposes. A control center and rod be located either around or just offset of the wheels but connected together, allowing for all 3 wheel systems to be connected and move in conjunction. This connection would then allow for one or two of the wheels to not be driven, using the torque of the other 1 or 2 motors to turn that wheel as well.

In summary, the final design will be able to traverse the entirety of the solar panel while dispensing solution and turning the brushes to be able to clean the panel. This design will eliminate the need for a person to do the manual labor of cleaning the solar panel.

Preliminary Design

Mechanical Engineering Components

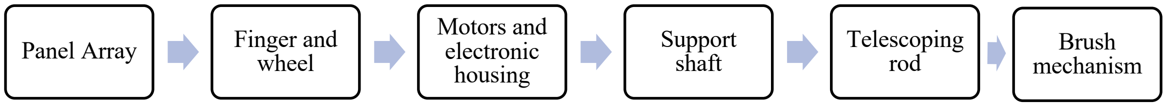

Figure 3: Mechanical Component Diagram

Since our product will be in a precarious location, our support system must be centered around using the array itself. To ensure the system is secure, our design will implement a 'V' wheel that is actually at 45°, allowing the wheels to travel along the top frame of the array. This can be seen in Figure 3. When conducting background research on the structure of roof arrays, we realized many systems have support beams running vertically along the back of the panel, which may interfere if we were to include this same wheel on the underside of the frame. We have considered making this wheel smaller as shown in the figure or removing it altogether and replacing it with a finger that will brush along the back of the frame, in case slippage was to occur.

The grey box shown in the figure represents the housing for driving motors and remaining electronics. The location of this box runs along the back length of our three support wheels and will balance forces to better secure our system. The two outside wheels will both be driven, ensuring there is no slipping when travelling either horizontal direction. We plan for these to be stepper motors allowing us to precisely control steps and thus location, therefore slipping or stalling would be detrimental to autonomous system functionality.

The center wheel is included for support of our extruding shaft. This shaft will connect our telescoping rod to the locomotion system, so it cannot rotate. We will need a bearing in this connection to allow wheel rotation around the stationary shaft. This will be the main point of connection for our cleaning components and allows us to balance all components from this center of gravity.

On the end of this stationary rod will be a telescoping pole. This will allow vertical motion and a waterproof location to run our controls to the brush. We plan for this rod to telescope about five times its original length of approximately a foot, which will be within the range of an average panel's vertical length.

At the end of our telescoping rod will be the brush system. We have discussed this system with a project advisor and have slightly simplified the design. Previously, we planned on having one central point of connection from the telescoping rod to the brush. There would be two brushes, extending either way from the center; each independently controlled by its own motor. This connection would include locking and a 90° rotation of the brushes, depending on the directions we send to the motors, allowing us to turn the brushes vertically to reach the panel area that would otherwise be unaccounted for underneath the telescoping rod, between the brush and wheels.

Rather than having one rotating point of connection to the center of the brush, we've decided to implement a rigid structure extending from the telescoping pole to either side of the brush, back-setting the brush to sit at the top of the panel when the pole is retracted. This allows us to account for that space from the beginning of each cycle, and is a much more simple solution that removes unnecessary complexity and motors from our design.

Component Requirements

- **90° v-wheel (3) : 3" outer diameter 0.6" inner diameter** : these will allow the robot to traverse horizontally across the top frame of the array. We have created some CAD models to simulate the average required wheel size, and used dimensions from wheels found on Amazon. Upon further evaluation however, we realized that this 'V' was not at 90° rendering these wheels useless for our application. This is not the only potential issue with the wheels we sourced from Amazon. These wheels are solid steel and would undoubtably damage a panel frame. Our original plan, regardless, was to 3D print these wheels ourselves and coat them in silicone to ensure protection of the panel frames.
- **Stability finger (3) : 3 inch length 0.5 inch width** : these fingers will sit on the bottom of the top frame of the panel, ensuring that if wheels slip there is another solid mechanical structure in place to prevent total separation from the array. This will likely be another custom manufactured part. We currently have high hopes that we can create a finger that allows deformation in the x-direction but is rigid in the y-direction. This will theoretically allow the finger to slip past any underlying structures that run the length of the panel, which are common amongst older systems.
- **Motors (X-direction motion)** : these motors will provide locomotive force in the x-direction, allowing the device to travel along the top of the array. These were chosen to be stepper motors as they track steps and will better let us gauge the devices location on the array.
- **Motor housing** : the motor housing is a vital structural component that will unite the two outer wheels, driven by steppers, to the inner wheel, whose rod is static and will support the telescopic brush. This will conveniently provide us with a dry location to store our

electrical components, along with the added benefit that its placement causes the housing to act as a counterweight for our system.

- **Connecting rod/shaft from motor housing to wheels and other components** – 16 inches length : this will be another custom manufactured part, and by far the most straightforward. This frame will further support the rotating and non rotating shafts, and allows a location for us to include bearings. Bearings are necessary for operation when moving and static shafts are to be attached to the same frame.
- **Five, 1.25 foot increments of a collapsing/telescoping rod of varying diameters to fit inside one another** – (Aluminum) (inner diameter of inner tube 2 in) (0.25 inch thickness) (next tube ID of 2.5 OD of 3) so on until (outermost tube ID 4 inches OD 4.5 inches) : the telescoping rod will likely be another custom manufactured component as we have had difficulty finding an already existing comparable technology. We have already run some tests with stepper motor linear actuators. These are essentially worm shafts driven by a stepper motor. As the shaft turns, a housing attached to the shaft travels linearly. We plan to implement a similar concept into the function of our system.
- **Cylindrical roller brush** (length: 1.5 ft) (diameter: 3-6 inches) : The roller brush will also be a custom manufactured part as we are unable to find an electric cylindrical brush. However, we know they are out there and will continue our search.
- **Small diameter metal structure** (triangular shaped) connecting to both ends of the cylindrical brush. Will be custom made. Hollow aluminum tube will be pressed on either end (to create flat surface). The tube will then be bent to shape and secured to either end of the cylindrical brush.

- **Motors (turning brush):** these motors will be inside the brush. We have chosen these as Dewalt drill motors.

Electrical Engineering Components

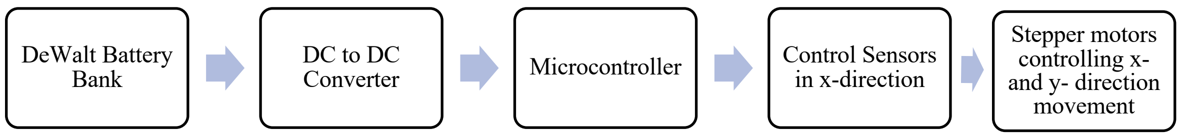

Figure 4: Block Diagram of Components on Top of Panel

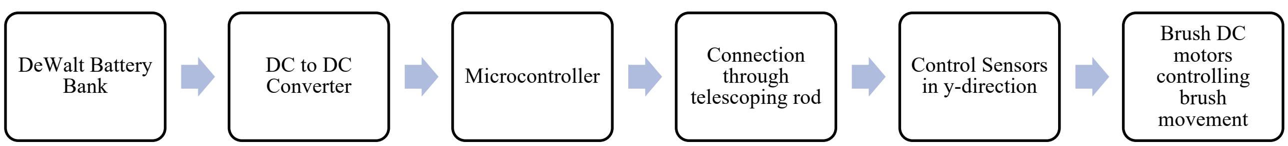

Figure 5: Block Diagram of Components on Brushes

The block diagram shown in figure 3 shows that our robot will be powered by DeWalt 20 Volt batteries. From there, the voltage will need to be stepped down from 20 Volts to 7-12 Volts so the microcontroller can be powered. The various voltage of 7-12 Volts is because the batteries are an unstable source of power due to the depletion of the batteries, the voltage can vary. The microcontroller decided on is an Arduino Leonardo. This Arduino has 7 output pins that can use pulse width modulation that will be able to control the speed of the motors. Then the microcontroller will control the sensors and the motors that are powering the robot's movement and brush movement. Two of the motors will be stepper motors and the other two motors will be bushed DC motors.

The stepper motor will be used to control the movement of the robot in the x-direction, which is across the panels to move the robot from one panel to the other. These motors will be located on the top of the robot to be closest to the x-direction movement. The brushed DC motors will be used to control the speed of the brushes that are cleaning the panel. These motors will be connected to the brushes on the robot so they can have direct control. They will be powered by a power cord going through the telescoping rod. The motor descriptions and motor controllers are descried in more detail below.

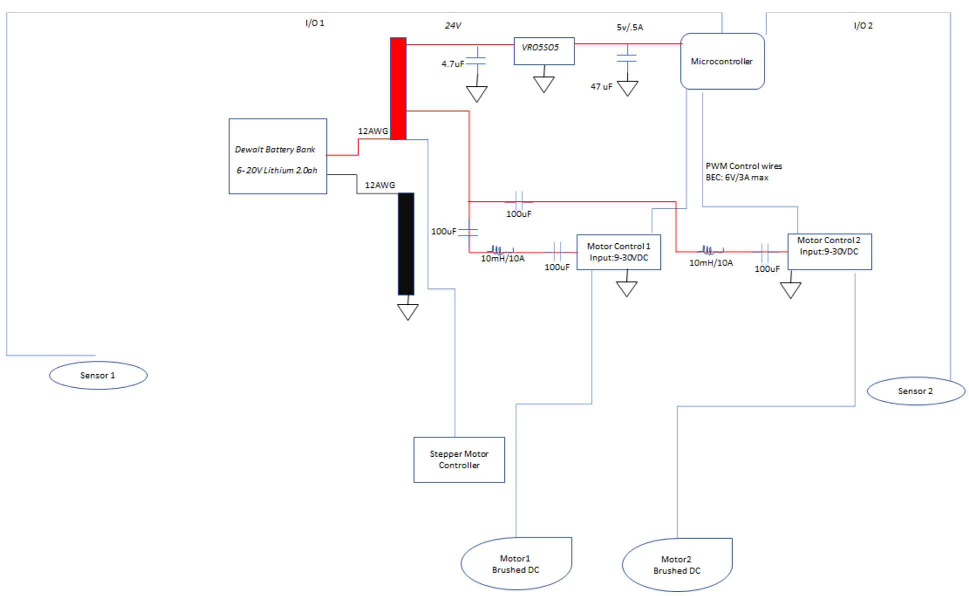

Figure 6: Circuit Diagram of Electrical Components

The circuit diagram in Figure 6 shows all the components in the Figure 4 block diagram working together.

Motors

Brush motors= For the brush motors the team will be using an OEM DeWalt 20V drill motor(N279939). This motor will provide enough torque for the brushes to spin at a high enough RPM value to ensure a proper cleaning. Another reason the group will choose to use this type of motor is that the group will have access to individual components such as adjustable chucks to hold a variety of attachments.

X-Axis Stepper Motor=For this component, the group will be using a stepper motor that operates at 24V. This motor will be used to move the robot system along the top edge of the array so the cleaning system can cover every inch of the array. By using a stepper motor the team will be able to control the speed and location of the robot to reduce overshoot or errors. At this time the motor has not been determined.

Y-Axis Motor= At this time, the motor to Control the telescoping rod has not been determined. The reason the group has not concluded on an exact motor is that the telescoping component is under design at this time. This motor will connect to the component to control the length of extension along the Y-Axis.

Motor Controllers

Dual Brush Motor Controller= Since DeWalt does not release specifications on their motors for patent purposes, the group will have to test the motor at a known load and voltage to determine the amount of current that the motor is drawing at full load. Once this is done, the team can determine the exact dual motor controller that will be used to perform pulse with modulation to gain the desired speed and efficiency of the system.

Power Source

DC Battery Bank Specifics = The style of DeWalt batteries that we have been provided with are 20V Lithium Ion 5AH batteries. This battery has 5 terminals that are used to individually charge each cell in the pack and read temperature. With the five terminals the team will only be using two of them denoted as

B- and B+ on the battery pack itself. By using only these two terminals the team will have access to a voltage of 20VDC for each individual battery. When it comes to wiring each battery, the team is planning to use four 5AH model DeWalt batteries or six 2AH batteries wired in parallel to increase the available ampacity and keep the voltage the same. The battery itself contains LG HB4 cells at 1500mA rated for 30A of discharge. The battery chemistry is NMC (Lithium Nickel Manganese Cobalt Oxide, LiNiMnCoO2).

Sensors

X-Axis Distance Sensor= To measure the robot's location for accuracy, the team will use a Lidar Lite V3 Garmin sensor. This sensor will provide the Arduino with the robot's exact location during the entirety of the cleaning process. By do this, the Arduino will know that the stepper motor is getting the proper contact and is moving along the array. Lastly this device will communicate with the Arduino to let it know when it has reached the end of the array. Once this signal has been received, the robot can complete its last cleaning cycle and then power down.

Y-Axis Distance Sensor= A sensor that will drop over the edge to reverse Y-Axis motor polarity.

Codes and Standards

OSHA Instruction PUB 8-1

Control Device: The following characteristics are essential for control devices:

1. The main control panel is located outside the robot system work envelope in sight of the robot.

2. Readily accessible emergency stops (palm buttons, pull cords, etc.) are located in all zones where needed. These are clearly situated in easily located positions and the position identifications are a prominent part of personnel training. Emergency stops override all other controls.

Installation, Maintenance and Programming: Good installation, maintenance, and programming practices include the following:

1. The robot is installed in accordance with the manufacturer's guidelines and applicable codes. Robots are compatible with environmental conditions.

2. Power to the robot conforms to the manufacturer's specifications.

3. The robot is secured to prevent vibration movement and tip over.

4. Installation is such that no additional hazards are created such as pinch points with fixed objects and robot components or energized conductor contact with robot components.

Average Weight on Solar Panels

The maximum weight that can be applied to solar panels is 40 pounds. Thus, our robot has to be under that weight limit to be considered safe for operation and not to damage the solar panel.

NEC Article 690 and Article 705

Articles stating the proper operation and safety of soler electrical systems. These articles also state that "qualified" individuals are the only ones able to operate solar systems on roofs.

Public Health, Safety, and Environmental Factors

Public Health, Safety, and Environmental Factors	Description
Environmentally friendly solution on panels	Nothing toxic can be used due to solution running down into the ground and on the roof of a customer's home
Safe proximity of electrical components to water	Components on the robot such as batteries, wires, motors and processors have to be sealed in a water-resistant container or be far enough from water
Security to array to ensure the device remains on the roof to prevent damage to customer's personal property or self	Disclaimer will be added in addition to fail-safes such as sensors to strongly recommend customers keep safe distance of surrounding areas while the robot is in operation

Insulated wires/moisture resistant wire	Wires insulated to avoid damage to wires or electrocution to user
Extensive volt meter testing	Voltmeter to test that circuits voltage is correct

Summary

In conclusion, our final design will be able to autonomously clean the solar panels without damaging them. The main points of our design come from our requirements which are clean, control, power, solution, and support. With all these satisfied, our team will be able to produce a product that satisfies the customer.

The most important parts of our design that need to work so the rest of the components can do their job is the support of the robot on the panel and the power supplied to the robot. With this in mind, our team will spend extra time and care on these parts to make sure our design works the way it should. With both mechanical and electrical components working together, this robot will be able to be completed and be different than every solar panel cleaner on the market right now.

References

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