Beyond Sunshine: Optimization of Solar Energy Production Using Automated Robot Control

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Connecticut Science Fair

Laboratory Notebook

2021-2022

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Topic: Idea Brainstorming **Date: 10/05/2021**

A crucial step in our project was to brainstorm ideas that can be solved using science, data, and engineering. Due to our experience in computer science and robotics, we created a list of multiple robotics-related ideas. We both decided on choosing a project that was energy related. With our mentor Mr. Katz, we explored options that would create an impact in the world of energy, whether that impact was towards the industry or everyday people. We discussed issues of power delivery efficiency, capacity factor of different energy sources, and more. After lots of discussion, we zoned in on three different ideas: A robot that travels along power lines and repairs/flags them, a drone equipped with vision analysis to flag areas of downed power lines, and a robot that traverses and cleans solar panels to maximize efficiency.

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Topic: Final Project Idea **Date: 10/12/2021**

After multiple days of deliberation, we decided that the best course of action for our project is to build a robot that traverses a solar field and cleans the solar panels whenever necessary. When comparing pros, cons, and relevance to society, this project emerged victorious, as green energy is becoming ever so popular and solar panels are an integral part of this multi-tiered solution to climate change. Having a robot that can make solar panels more efficient via cleaning will immensely help the push for green energy, as it will increase the efficiency of its energy generation. This will make it a more sought for source for residential and commercial energy generation. Also, we considered a multitude of design possibilities, such as having only the cleaning components move from panel to panel while the hubs stay on the edge of the row, to reduce the risk of damage to the robot's electrical systems. Furthermore, with advice from our mentor Mr. Katz, he suggested making some sort of process to check whether or not the panel is damaged. One method is to have a thin object run across the panel and if were to shift slightly downward at a spot a scratch would be detected. However, we decided that our robot should operate in an entirely touchless fashion. Because of this, we decided against adding something that would make contact with the solar panel. But, we decided to add a function to the robot's code where it can flag a specific panel that continues to produce abnormal energy output despite being cleaned and having the appropriate weather conditions.

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Topic: Testing Cases and Methods **Date: 12/07/2021**

Today, we went over how we should test and collect data for our project. Initially we wanted to ask a solar panel company to donate or loan a panel, however we deemed it somewhat unnecessary. This is because it would take a while to obtain one, and it wouldn't be the easiest thing to set up for testing with all the electronics, energy sensors, and other technologies behind the solar panel. Furthermore, it would be harder to transition between the different test cases on an actual solar panel because the glass is permanently attached to the panel.

Our school has a good amount of polycarbonate from past projects. So, we decided to use them to simulate the surface of a solar panel. This worked well since we could cut different panels for different cases so the debris doesn't mix and mess up the data. To simulate the energy output of a solar panel, we plan on using light sensors to measure the illuminance of the light passing through the polycarbonate.

We will use four pieces of polycarbonate to show the illuminance under optimal conditions, debris (grass, twigs, etc.), dirt, and water. One thing we have to consider is how we plan to mount everything, and what we're going to use as a base.

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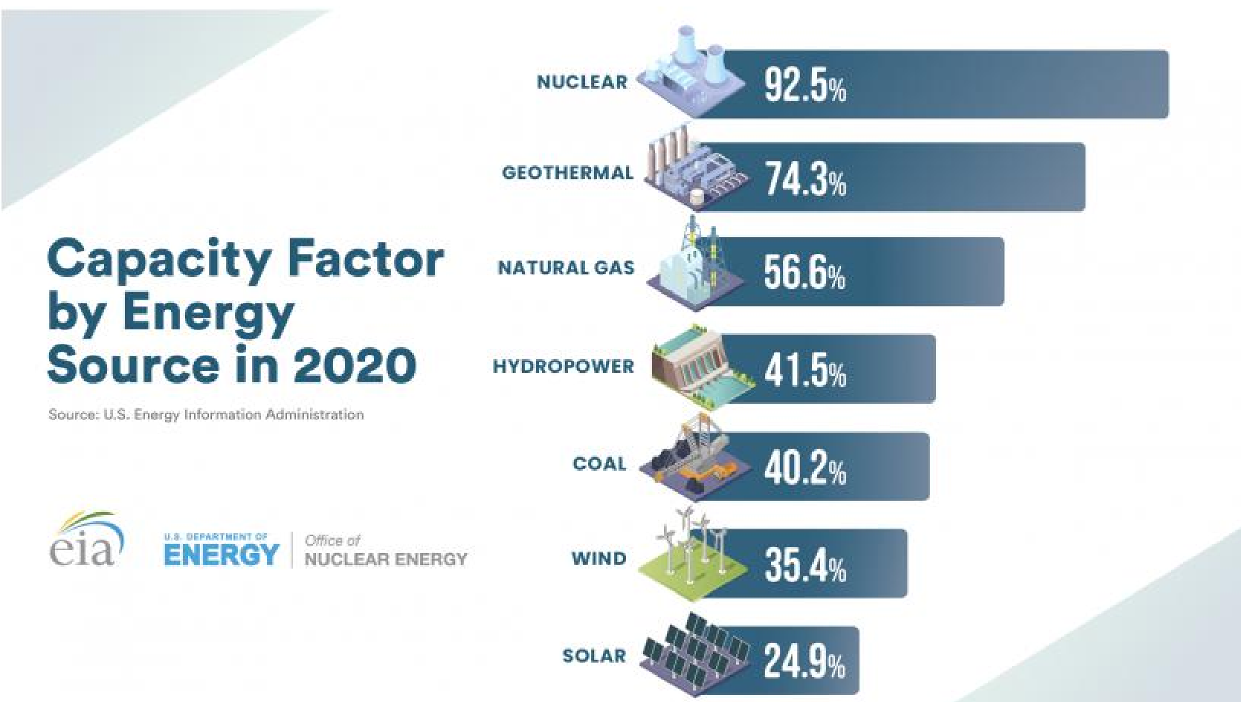
Topic: Capacity Factor of Solar Panels **Date: 12/14/2021**

Continuing our research towards solar panels, we found an important element known as the capacity factor. The factor is displayed as a percentage which shows how often energy is generated at maximum capacity. So, in our case, solar panels have a capacity factor of 24.9%. This means that it operates at maximum capacity only 24.9% of the time whereas resources like coal and nuclear have a capacity factor of 40.2% and 92.5% respectively (according to energy.gov). One reason this capacity factor is relatively low is because of the interference and presence of particulate matter and obstructions. With our project, we seek to reduce this factor as much as possible to increase the efficiency and overall energy generation of solar energy. As the world progresses to the use of green energy, making these sources as efficient as possible will accelerate the global switch to renewables.



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Topic: Robot Prototype Design **Date: 01/04/2022**

As of now, we have yet to get the appropriate parts for the robot, nor was it practical to make a fully functioning design in such little time. Knowing this, we agreed to make a prototype to somewhat mimic the design we were going for. To accomplish this we plan to use the VEX robotics kits from another class. While looking through the storage closet we came upon several robot parts we needed, batteries, controller, gears, luckily we also found a foam piece that would fit perfectly for our project.

From this we designed our testing rig so the light sensors would be placed one side in a X formation which helps us get the illuminance from a decent spread. The other side we plan to have the robot mounted so whenever we want to clean it, the robot can easily access the panel.

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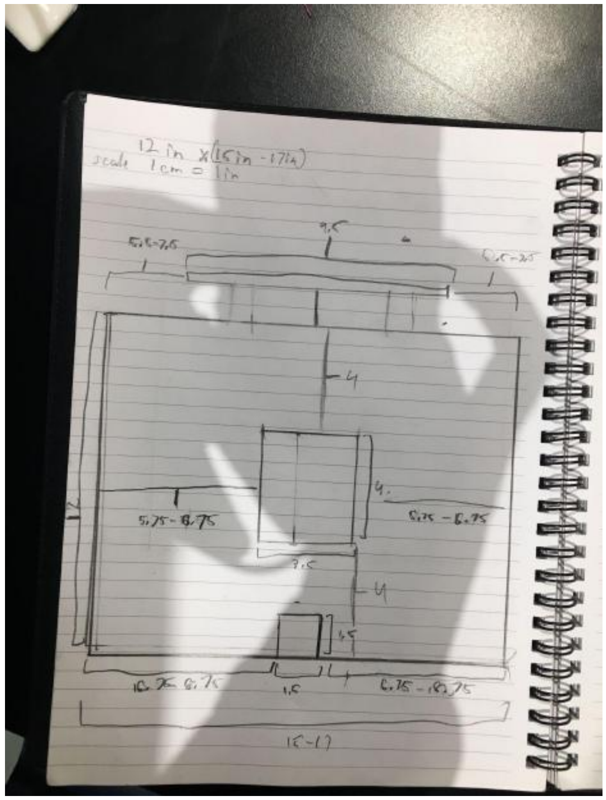
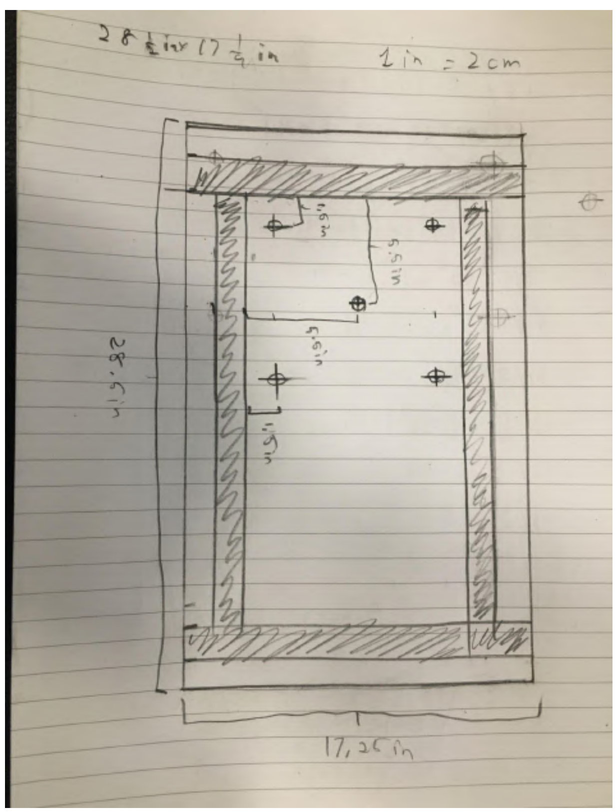
Topic: Robot Prototype and Testing Rig Sketches **Data: 01/04/2022**





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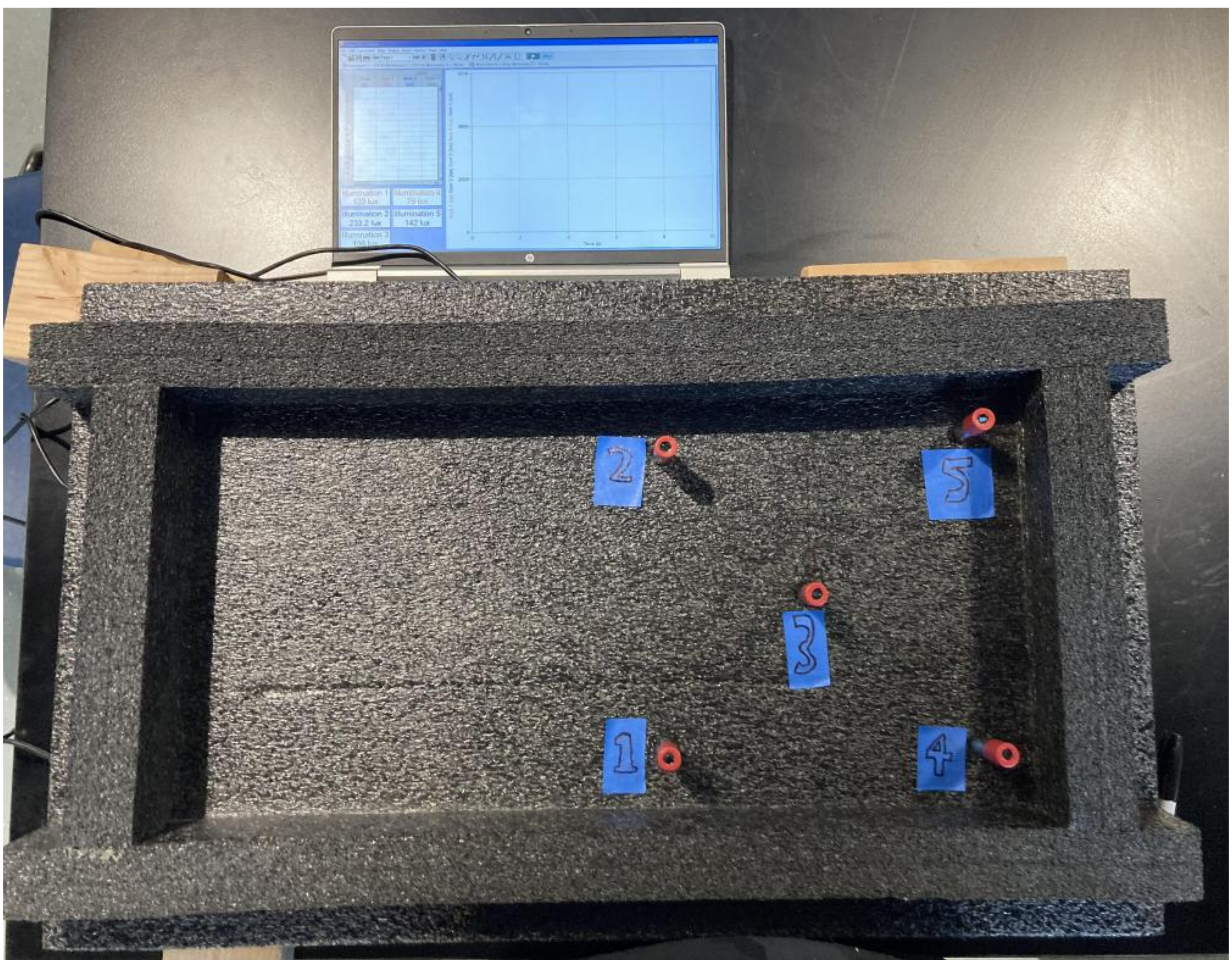
Topic: Testing Rig Base **Date: 01/27/2022**

Today, my partner and I completed final placements of light sensors, as well as cable connection and organization. Furthermore, we assembled the support system for the testing rig, which will elevate the testing rig about 5-6” off the ground. This allows the wres for the light sensors to be easily routed underneath the testing rig. Finally, we started our assembly of the drivetrain portion of our robot. We will be using 2 motors to indirectly power 4 wheels. This reduces the number of motors needed, reducing clutter and complexity.



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Topic: Cutting of Polycarbonate for Testing **Date: 02/02/2022**

Today, we worked on gathering and preparing our polycarbonate for preliminary testing. We gathered our polycarbonate, measured out 4 12” x 12” squires, and cut them out to that rough shape. After that, we cleaned all the pieces of polycarbonate with soap and water to eliminate any residue that has the ability to affect our data collection. Given that this is an old sheet of polycarbonate we need to test them all to see if there are major differences due to damage such as scratches and smudges.

We’re also reconsidering the types of debri we should test. Originally we decided to test dirt, mud, and water with the last panel being our control one. However when considering the environment a solar panel, it isn’t realistic for mud to ever get on a panel. So we decided to replace mud with physical debri such as leaves and twigs.

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Topic: Testing Polycarbonate **Date: 02/09/2022**

We started by testing the different polycarbonate panels that we had to determine if there was any negligible difference in data caused (Refer to Appendix A) by the scratches on the panels. It was determined that there is a small difference in lumination caused by the scratches. But, data collected using the panels will still be accurate as long as there is one panel of polycarbonate acting as a control variable.

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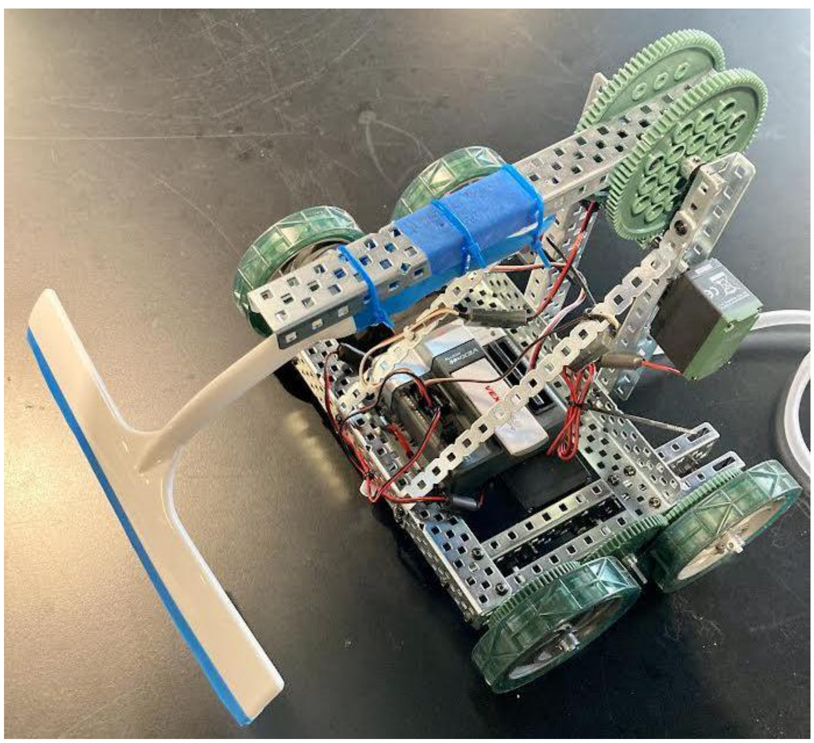
Topic: Robot Prototype Building **Date: 02/11/2022**

We built the base for our robot and established a two-motor drivetrain with an arm that will hold the squeegee (for cleaning debris and snow). Also, we completed some preliminary testing outside to determine if the environment outside was stable and feasible for our project. After our testing (with a sunny sky), it's determined that the outside is a feasible environment to test in. Finally, we learned that some of our light sensor modules are recessed into the housing of the light sensor. This causes a shadow to be casted on the sensor module when the light source isn't casted directly above the testing rig, which causes an inconsistency in readings (as shown in the readings of sensor 3 and 5). To fix this, the light source will be stationed directly above the sensors, and we will replace the recessed light sensors with others that have the modules closer to the top of the housing.



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Topic: Testing Effects of Debris and Cleaning **Date: 02/23/2022**

Today, we completed all our necessary testing with a control, debris, dirt, water, and no panel (see Appendix B). The testing was completed outside with partly cloudy weather. One problem with using the sun as our source of light is the variability which can cause some inconsistencies with our data.

We started each trial measuring the input with no polycarbonate present to get a general reading, followed by the control panel to compare with the other panels (polycarbonate). We would then apply the necessary form of debri to the appropriate panel and repeat for the other panels.

For the second phase of testing (See Appendix C), we initially recorded the illuminance of the dirty panel. After cleaning it we remeasured and recorded the new output which will be compared to each other for our final data.

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Topic: Pseudo Code **Date: 02/24/2022**

While wrapping up the project we figured we can generate a pseudo code to illustrate the process used to automate the system (See Appendixes D-F). This includes 3 java classes SolarPanel, SolarField, and Robot.

The purpose of the SolarPanel class is to compile the data of one solar panel which can determine whether or not a solar panel should be cleaned or not. This considers factors such as energy output, the UV index, and weather in order to prevent the robot from running unnecessarily.

The SolarField class contains several SolarPanel objects (from the SolarPanel class) to represent the solar panels within the field. This is used to help the robot traverse the field considering the distance between panels, and the amount of rows and columns in the field.

Last but not least, the Robot class considers the robot’s mechanical features including motors and servos which control the robot's movements.

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Topic: Data Compiling **Date: 02/28/2022**

The last step, aside from making the poster, is now to compile the data. It was decided that the most effective way to refer to the data would be to mention changes due to the presence of debris or the process of cleaning the panel. To do so we took the sum of the illuminances from the five sensors to represent the total energy output and compared it to the necessary panel. For the change due to debri the total illuminance between the panel in question and the control were compared, whereas for the cleaning test the cleaned panel was compared to the unclean panel (see Appendixes B-C).

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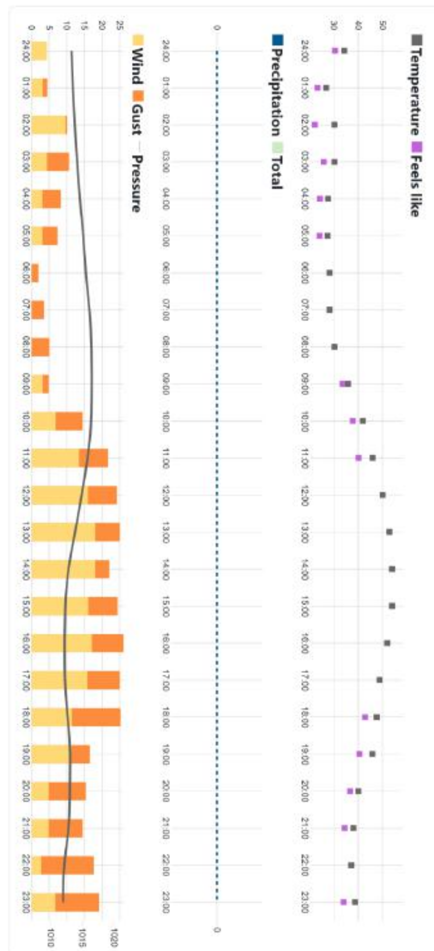
Appendix A

Testing to determine if scratched polycarbonate produced a negligible difference

- **No Panel:**
  - Sensor 1: 192 lux
  - Sensor 2: 277 lux
  - Sensor 3: 149 lux
  - Sensor 4: 106 lux
  - Sensor 5: 188 lux
- **Panel 1:**
  - Sensor 1: 160 lux
  - Sensor 2: 237 lux
  - Sensor 3: 120 lux
  - Sensor 4: 106 lux
  - Sensor 5: 158 lux
- **Panel 2:**
  - Sensor 1: 162 lux
  - Sensor 2: 235 lux
  - Sensor 3: 126 lux
  - Sensor 4: 88 lux
  - Sensor 5: 160 lux
- **Panel 3:**
  - Sensor 1: 162 lux
  - Sensor 2: 234 lux
  - Sensor 3: 126 lux
  - Sensor 4: 80 lux
  - Sensor 5: 157 lux
- **Panel 4:**
  - Sensor 1: 162 lux
  - Sensor 2: 235 lux
  - Sensor 3: 126 lux
  - Sensor 4: 96 lux
  - Sensor 5: 159 lux



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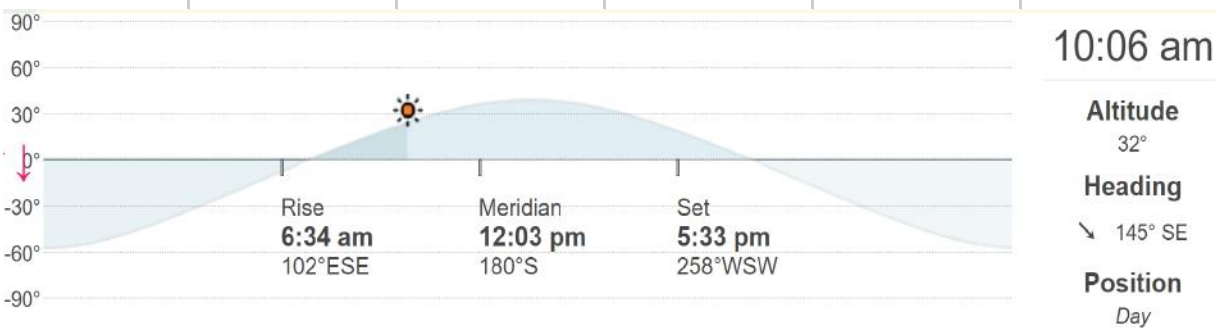
Appendix B

Illuminance Levels With Contaminated Panels

Trial 1:

Trial 1	No Panel	Dirt	Debris	Water	Control
Sensor 1	22101	17498	16850	20585	18530
Sensor 2	20400	15581	7432	18624	16516
Sensor 3	16695	5110	3773	15396	13942
Sensor 4	18911	2287	11116	17850	16161
Sensor 5	18049	10445	14060	16279	15047
Total Illuminance	96156	50921	53231	88734	80196
Average Illuminance	19231.2	10184.2	10646.2	17746.8	16039.2
Percentage Differential from Control Test Case		-37%	-34%	11%	



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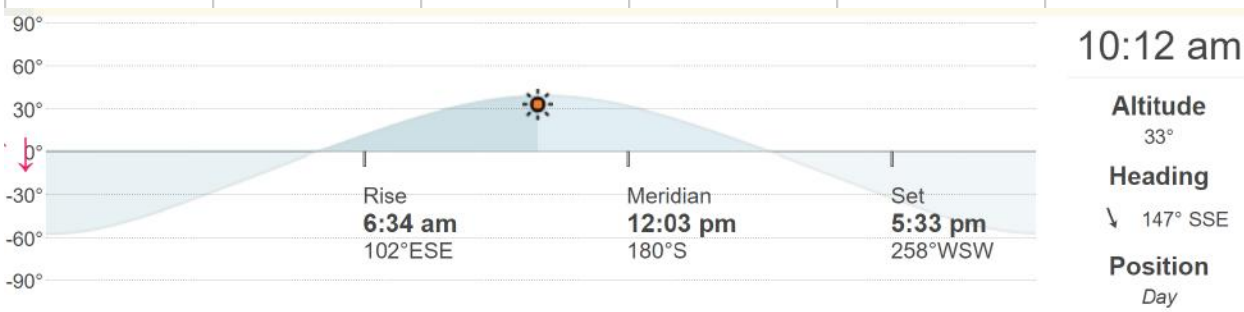
Trial 2:

Trial 2	No Panel	Dirt	Debris	Water	Control
Sensor 1	25320	10744	10513	19887	19955
Sensor 2	22637	13221	10311	17871	17689
Sensor 3	18463	6892	8776	14795	14699
Sensor 4	21758	7335	12487	17044	17275
Sensor 5	20248	9097	13695	16021	16062
Total Illuminance	108426	47289	55782	85618	85680
Average Illuminance	21685.2	9457.8	11156.4	17123.6	17136
Percentage Differential from Control Test Case		-45%	-35%	0%	



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Appendix C

Illuminance with Cleaned Panels:

Cleaning Test	Panel 1 (Clean)	Panel 1 (Dirt)	Panel 2 (Clean)	Panel 2 (Debris)	Panel 3 (Clean)	Panel 3 (Water)
Sensor 1	25746	22793	21951	13975	24569	23229
Sensor 2	27130	21682	20600	20497	23009	21886
Sensor 3	26412	14910	15883	11061	17724	16751
Sensor 4	24951	17399	16985	9041	19629	18557
Sensor 5	24576	16504	16997	16809	18949	17903
Total Illuminance	128815	93288	92416	71383	103880	98326
Average Illuminance	25763	18657.6	18483.2	14276.6	20776	19665.2
Percentage Differential Between Clean and Unclean	38.08%	0%	29.46%	0%	5.65%	0%

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Appendix D

SolarPanel Class:

```
Public class SolarPanel{

        private double currentOutput;
        //How much energy the solar panel is producing in kW


        private double normalOutput;
        //How much energy is typically produced in kW


        private double factor;
        /*if the difference of the current and normal output is greater than the factor, the robot will
        consider cleaning the robot. Will be determined through the test
        */


        private double uvIndex;
        //Compares UV index in order to rule out air quality, so if the index is lower than a lower output is
        expected.


        private String weather;
        //Provides current weather, so if it’s cloudy or raining a lower output is expected


        private int zipCode;
        //Used to get weather in the location
```

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```
    public SolarPanel(double currentOutput, double normalOutput, double factor, double uvIndex,
    String weather; int zipCode){
        //Makes SolarPanel object with given variables
    }

    public SolarPanel(){
        /*Makes a blank spot on SolarField where a panel is not present in the event the they
        aren’t distributed in a rectangle
        */
    }

    public getCurrentOutput(){
        return currentOutput;
        //Similar method used for all variables
    }

    public static boolean needToRun(SolarPanel check){
        if(check.getNormalOutput - check.getCurrentOutput < check.getFactor &&
        check.getUVIndex > 7.0 && check.getWatherAt(zipCode) == “Sunny”){
            return true;
        }
        return false;
    }
}
```

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Appendix E

SolarField Class:

```
public SolarField{

    private int rows;

    //How many rows of panels there are


    private int column;

    //How many columns of panels there are


    private int panelLength;

    private int panelWidth;


    private double distance

    //Distance between panels, used for traversing;


    private SolarPanel[][] solarField;

    //creates a 2-dimensional array to simulate a solar field


    private int[][] currentPosition


    public SolarField(int row, int column, double distance){

        //Takes user input for SolarField

        //manually put in values for each panel
```

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```
    }

    traverse(int newRow, int newColumn){
        /*considers current position, newRow, newColumn, panelLenght, panelWidth,
        and distance to accurately move
        */
    }

}
```

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Appendix F

Robot Class Pseudo Code:

```
public class Robot{

    private motor rows;

    private motor columns;

    private motor hose;

    private switch airCompressor;

    private servo Squeegee;

    for(eachPanelInSolarField){

        if(SolarPanel.needsCleaning() == true){

            traverse(newPosition);

            clean();

            returnToHome();

        }

    }

    private clean(){

        //Moves robot using travers method from SolarField class


        //uses cleaning materials in order

    }

    private returnToHome(){

        //moves back to original spot

    }

}
```

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