Sun Tracking Solar Panel Array For Arctic Applications

ECE 445 Design Document

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1. Introduction

1.1 Objective

The use of renewable energy has steadily increased over the past years as the world moves to decrease carbon emissions. The United States currently has 17.5% of its energy usage sourced by renewable sources 1.8% of the total energy consumption being solar energy [1]. For the United States to lessen its carbon emissions, the usage of renewable sources like solar needs to become more commonplace. Adding more solar energy to the grid has its complications. One such challenge is the fluctuation and accessibility of solar energy. The sun is only out for a portion of the day, but, in many cases, is obscured by clouds. These limitations make solar more accessible to locations like the Southwestern United States. For the United States to lower its carbon emissions, solar energy needs to be more accessible to places such as Alaska. Currently, Alaska gets a small fraction of its energy from solar. Most solar energy in the state is off the grid and primarily used in remote villages for heating [2]. In regions such as Alaska, where year-round sunlight is not as readily available solar panels need to extract as much energy from the sun as possible.

Our goal is to create a solar panel array that can help make solar energy more accessible to places like Alaska. We intend to do this by making a solar panel array that will autonomously track the sun throughout the day using a microcontroller, ensuring that even in the cold climate of Alaska, the system will still function by heating the components that could freeze in that climate.

1.2 Background

Solar panels that track the sun are in use in many industrial applications today; sun-tracking arrays can provide a 25-35% increase in overall efficiency [3]. Tracking solar panel systems are not as in use in residential applications, making residential systems less efficient. Tracking Systems are generally larger and heavier than a fixed panel system. Our goal here is to make it light enough that it can mount on rooftops.

1.3 High-Level Requirements

- The system must be able to withstand “Arctic” temperatures as low as -35∘C.
- The system must be powered at all times. Either from the battery source or the solar panels.
- The system must be at least 15% more efficient than a fixed solar panel array in terms of energy production.

2. Design

The arctic solar panel array has four essential sections of operation: the power unit, control unit, movement unit, and temperature control unit. The power unit ensures a constant supply of power to the other components: 5V to the microcontroller or 12V to the tilt and pivot motor. The control unit houses the microcontroller and calculates the sun's position and tells which relay should be on or off. The movement module will position the solar panel array based on the inputs from the control module. The temperature unit will maintain an optimal temperature to keep the overall system running smoothly.

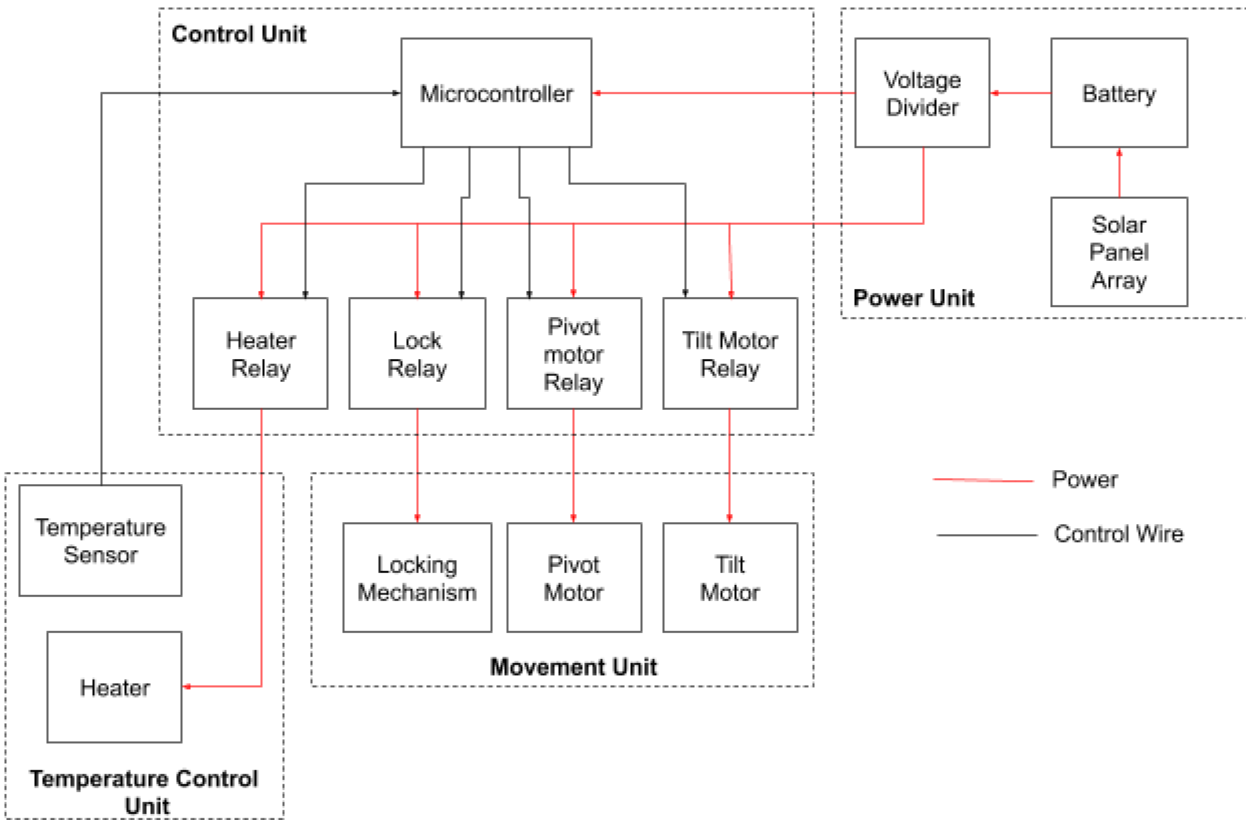

Figure 1. Block Diagram

The physical design as shown in figure 2, will consist of a solar panel mounted to a pivot that will allow for the tilt to behave smoothly. The mount also consists of a vertical pole that will be used to mount the tilt motor to and connects to the base plate. On the base plate is the controller enclosure which will house the PCB, battery, and microcontroller.

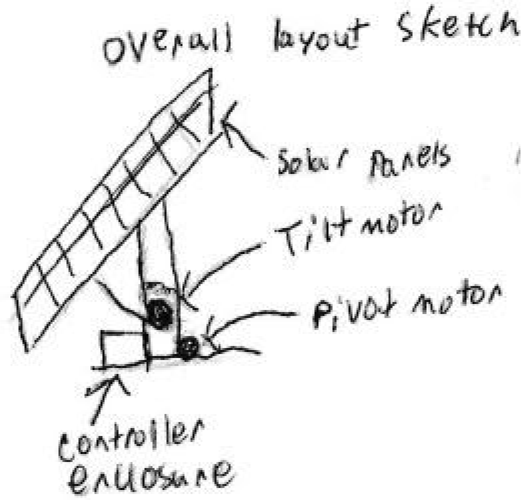

Figure 2. Overall Layout sketch

2.1 Power Unit
The power unit is required to get energy from the solar panel array and supply power to the rest of the system.
2.1.1 Battery
The battery powers the motors, heater, and microcontroller. While the Solar Panel charges the battery, the battery maintains the power requirements of the rest of the system. It will be used during the night time to keep the heater on for the solar panel.

Requirement	Verification
The battery must supply >500mAH of charge at 18V +/-5%	A. Connect a fully charged battery to the system B. Discharge battery at 100mA for 5 hours C. Use a voltmeter to ensure the voltage remains within the 18V threshold

2.1.2 Voltage Divider
The Voltage Divider will allow us to create the required voltages for our circuit to operate the microcontroller (5V), the motors (12V), and the locking mechanism. The heating coil will require a different voltage as well as adjusted based on temperature.

Requirement	Verification
1. Provides 5V +/- 5% and 12V +/- 5% from an 18V source with currents from 0-150mA 2. Can operate at temperatures below -35°C	1. Connect the input to an 18V source and draw 150mA 2. Using a voltmeter measure the two outputs to ensure the output voltages are within 5% of 5V or 12V

2.1.3 Solar Panel Array

The array in mind will be four panels that will charge the battery with enough power so that it can power the rest of its components with excess energy going to the grid.

Requirement	Verification
Outputs 150mA - 200mA between 8V and 9V in full sunlight. (100,000 lux)	1. Place the solar panel array in 100,000 lux light. 2. Measure the open circuit voltage with a voltmeter ensuring the voltage is under 9V 3. Terminate the solar panel with a load that ensures a voltage drop of 8V 4. Ensure the current through the load is above 150mA using an ammeter

2.2 Control Unit

The control unit houses the microcontroller as well as the relays used to control each component. The control unit receives the outside temperature as an input from the temperature sensor. The control unit outputs the correct motor positions to the movement unit as well as power to the movement unit. Since this is designed for arctic climates like Alaska the Sun’s position in this document is calculated by using the latitudes of Anchorage, Fairbanks and Juneau Alaska as well as the latitude of the Arctic Circle.

2.2.1 Microcontroller

The microcontroller will calculate the position of the sun and output the signals needed to move the solar panel array to the correct degree. These control signals include the enable/disable that goes to each relay and the positioning information to the motors.

Requirement	Verification
1. The microcontroller must accurately calculate the sun's position in the sky 2. The microcontroller must be able to run at -35°C	1. A. Verify that the tilt angle value calculated matches the value calculated by the equation: $Tilt\ Angle = 90° - \beta$ B. Verify that the calculated azimuth angle matches the angle given by the equation: $\phi_s = arcsin(\frac{cos(\delta)sin(H)}{cos(\beta)})$ 2. A. Set the microcontroller in a freezer or a cooler that has a temperature of -35°C B. Use verification steps from 1. To determine functionality.

2.2.2 Heater Relay

The heater relay will receive an enable/disable signal from the microcontroller. When enabled, the heater will send power to the heater.

2.2.3 Lock Relay

The lock relay receives an enable/disable signal from the microcontroller. When enabled, the lock relay will send power to the locking mechanism, disengaging the lock allowing for the array to move.

2.2.4 Pivot Motor Relay

The pivot motor relay controls the power input to the pivot motor. The pivot motor relay will receive an enable/disable signal from the microcontroller. When enabled, the relay will send power to the pivot motor so the array can move.

2.2.5 Tilt Motor Relay

The tilt motor relay controls the power input to the tilt motor. The microcontroller sends an enable/disable signal to the relay. When enabled, the relay will send power to the tilt motor allowing the array to move to the correct position.

2.3 Movement Unit

The movement unit contains the motors needed to move the array to the correct position. This position is given to the movement unit by the microcontroller. Once in the proper position, the locking mechanism engages, and the unit shuts down while it waits for another signal.

2.3.1 Locking Mechanism

Once the Motors have achieved an optimal placement, it is beneficial to have a locking unit to be able to turn the motors off with their respective relays rather than having them maintain their position in place and using more energy.

Requirement	Verification
The Locking mechanism should lock within 2 +/- 0.5 seconds of the motors moving to a new position.	A. Move the motors to a position +/- 10° from the current position B. Start a timer to timer once the motors stop moving C. Stop the timer when the locking mechanism closes and ensure time does not exceed 2.5 seconds

2.3.2 Pivot Motor

This motor will control the pivot of the actual array to maintain the optimal angle between itself and the sun during the day. The motor needs to have a range of motion to support the azimuth angles as shown in figure 3. This is calculated using the equation $\phi_s = arcsin(\frac{cos(\delta)sin(H)}{cos(\beta)})$ where ϕ_s is the Azimuth angle, δ is the solar declination angle, H is the degrees from solar noon, β is the altitude angle[5].

Requirement	Verification
1. The pivot motor will move the array to within +/- 2°	A. Send a pivot position to the motor from the microcontroller B. Using a protractor measure the angle of the motor position and ensure that the angle is within 2° of the angle given by the microcontroller

2.3.3 Tilt Motor

This motor will control the tilt of the actual array to ensure the optimal angle between itself and the sun during the day. The motor needs to have a range of motion that supports the range of degrees given in figure 4. The tilt position is calculated using the equation: $Tilt\ Angle\ =\ 90° - \beta$ where β is the altitude angle of the sun.

Requirement	Verification
The tilt motor will move to be within +/-2° of the tilt angle given by the microcontroller.	A. Send a pivot position to the motor from the microcontroller B. Using a protractor measure the angle of the motor position and ensure that the angle is within 2° of the angle given by the microcontroller

2.4 Temperature Control Unit

The temperature control unit monitors the outside air temperature and will keep the system at the necessary temperature to operate in the arctic climate.

2.4.1 Temperature Sensor

The temperature sensor reads the outside air temperature and sends it to the microcontroller.

Requirement	Verification
A continuous feedback loop exists between the temperature sensor and microcontroller that enables the heating unit once the sensor detects that the temperature dips below 0 degrees Celsius	The microcontroller constantly polls the temperature sensor to detect a temperature dip. Once it starts approaching 0 degrees celsius the heater turns on to prevent the temperature from actually dropping below 0

2.4.2 Heater
When the outside air temperature is below 0°C the heater will turn on, allowing it to keep the system warm so it can operate in the sub-zero temperatures.

Requirement	Verification
When the outside air temperature is below 0°C, the heater must keep the control enclosure and motors at or above 0°C	A. Set the system in a freezer that is below 0°C for 5 hours B. Measure the temperature of the motors and the control enclosure to ensure the temperature is at or above 0°C

2.5 Tolerance Analysis

To maximize the efficiency in a solar panel array the solar panel should be able to track the sun across the sky. Maximizing the efficiency of the solar panels is essential to the increased usage of green energy. Gaining the most energy from the solar panels is even more important in regions that receive less sun throughout the year. One such region where the sunlight does not shine as often or as intense is Alaska.

To maximize the efficiency of the panels in Alaska the panels must be able to track the sun across the sky. To do this the motors and the mechanism needs to have a range of motion where the panels can consistently receive the most sunlight. The solar panels track the sun using two angles, the altitude angle and the azimuth angle.

The altitude angle is used to calculate the tilt angle of the solar panels. The altitude angle is calculated using the solar declination angle and the latitude of the solar panel. The solar declination angle is the relationship between the tilt of the Earth's axis and the sun's position [5]. This angle varies as a sinusoid that depends on the day of the year. This equation is shown below as Eq. 1 where δ is the solar declination angle and n is the day of the year.

$$\delta = 23.45 sin(\frac{360}{365}(n - 81)) \quad \text{Eq. 1}$$

With the solar declination angle the altitude angle can be calculated. The altitude angle is how high the sun is in the sky and can be directly used to calculate the tilt angle. The altitude angle is calculated using Eq. 2 then the altitude angle is used to calculate the tilt angle as shown in Eq. 3.

$$\beta = 90° - L + \delta \quad \text{Eq. 2}$$

$$Tilt\ Angle\ =\ 90° - \beta \qquad \text{Eq. 3}$$

Using these equations Figure 3 shows the tilt angle throughout the year of a solar panel array at the latitudes of cities in Alaska and the latitude of the arctic circle. The tilt motor and the mechanism that the solar panel tilts on needs to be able to move to every possible angle that the panel needs to tilt to. The tilt angle is between 89.9° and 34.8°. The tilt mechanism should be able to extend past these values by 5% making the needed range of motion of the tilt 94.39° to 33.06°.

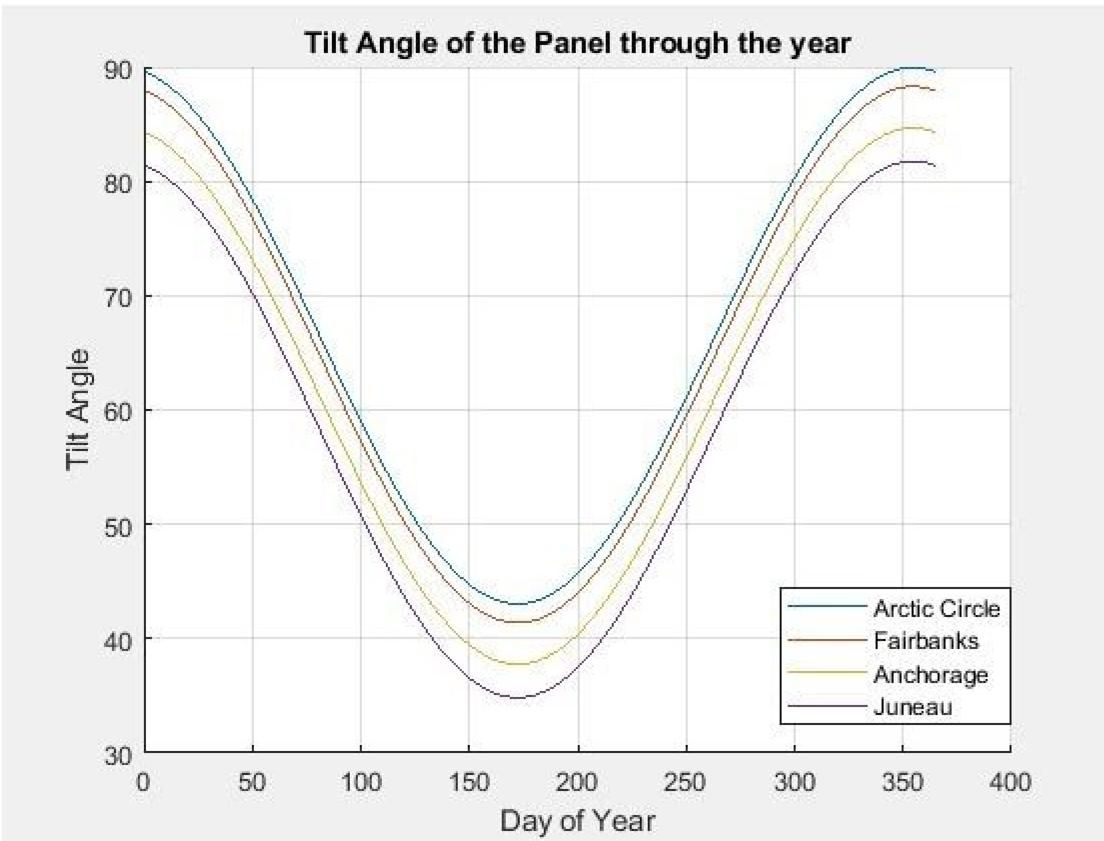

Figure 3. Tilt angle throughout the year

The second degree of freedom that the solar panel array needs is the pivot. The pivot angle is the angle between the sun's position East or West of due South (solar noon). This angle is called the azimuth angle and is calculated using Eq. 4. Where ϕ_s is the azimuth angle and H is the hour angle. The hour angle is calculated using Eq. 5 where the hour is negative after solar noon and positive before solar noon. Using these equations a plot of the azimuth angle throughout the year one hour before solar noon and at latitudes of Alaskan cities and the arctic circles is shown in Figure 4.

$$\phi_s = arcsin(\frac{cos(\delta)sin(H)}{cos(\beta)}) \qquad \text{Eq. 4}$$

$$H = 15° * (hours\ before\ or\ after\ solar\ noon) \quad \text{Eq. 5}$$

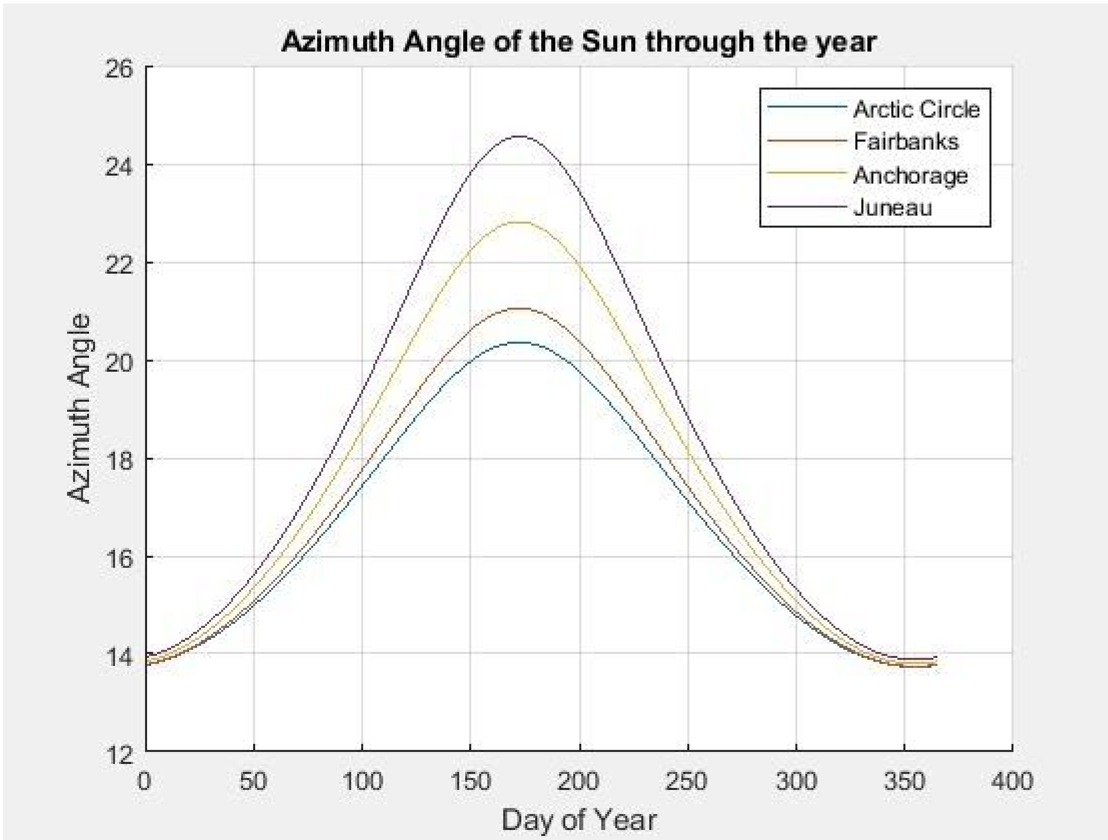

Figure 4. Azimuth angle throughout the year

2.6 COVID-19 Contingency Plan

With Covid-19 our plan as of now is reliant on the idea that we won't have to turn virtual where the University turns to full online instruction. If such an event would occur Ashhal and Zayd would no longer have access to the lab, but Brandon would remain unaffected because he is online. Working separately will not be ideal for physical design, so it may be better to create CAD models of every individual component and piece them together through the CAD software. This will allow us to prototype, to some degree, the actual mechanisms of our project while maintaining our current project as best we can being in three separate locations. While we may not be able to fully create the device, having a functioning CAD model should demonstrate our project in its entirety as well. We can also run simulations of the electronics to show that the electrical parts of the device would work if it was a physical board.

3. Cost and Schedule

3.1 Cost Analysis

Part	Vendor	Quantity	Cost
EK-TM4C123GXL Microcontroller	Mouser Electronics	1	$15.59
Sunnytech .5w 5v small solar panel	Amazon	4	$27.96
PB1247-ND 5v SPST-NO relay	Digi-key	4	$18.64
BYV26C-TAPCT-ND Diode	Digi-key	4	$2.44
9 Volt Rechargeable batteries	Amazon	1	$13.99
PCB	PCBWay	1	$3.10
Temperature Sensor LM135AH	Texas Instruments	1	$21.46
		Total	$103.18

3.2 Schedule

Week	Brandon	Ashhal	Zayd
9/29/20	Continue circuitry design	Find compatible temperature sensor	Begin ordering parts
10/5/20	Run simulations of design	Run and test design simulations	Run and test design simulations
10/12/20	Design PCB	Start programming on microcontroller	Start programming on microcontroller
10/19/20	Run Additional Simulations as necessary	Begin Verifying parts are working as intended	Begin Verifying parts are working as intended
10/26/20	Make Revisions to PCB	Program Microcontroller. Test with PCB	Program Microcontroller. Test with PCB
11/2/20	Test revised PCB	Assemble mount and position motors	Assemble mount and position motors
11/9/20	Final Assembly of project	Final Assembly of project	Final Assembly of project
11/16/20	Performance Testing and Verification	Performance Testing and Verification	Performance Testing and Verification
11/23/20	Work on final Presentation	Work on final Presentation	Environmental Testing
11/30/20	Finishing touches and Presentation	Finishing touches and Presentation	Finishing touches and Presentation
12/17/20	Work on Final Paper	Work on Final Paper	Work on Final Paper

4. Safety and Ethics

While there are not many safety and ethical hazards that come along with our project, there are certainly some notable ones. Firstly, our design utilizes 9V lithium-ion batteries, which are usually safe but can result in potentially dangerous behavior. A larger issue is battery failure or even an explosion as our design is for use in significantly colder temperatures. To avoid this possibility, we have a heater that regulates the temperature of the entire product.

A similar issue regarding the rechargeable battery is the potential for overcharge, resulting in an exothermic reaction. For this reason, we ensure that the battery does not charge beyond 8.5 V, to allow for a comfortable buffer in an emergency.

While our design is relatively small, we are going to attempt to make it as sturdy as possible by maintaining the majority of the weight at the bottom of the product. In practice, however, our design is going to be used in a much colder environment with high-speed winds, which may result in the structure falling over and injuring people and potentially animals. To remedy this, we are going to have the assembly embedded in the ground, anchoring itself deep to prevent falling over while also using some of that underground heat to regulate temperatures.

While we are investing all resources to avoid accidents, the IEEE code of ethics category that best applies to our design would be II.9: “to avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses” [4], which is ensuring that our design prevents infliction of any form of harm on any other individual through a lack of structural integrity, which we believe that our prevention practices align with I: “To uphold the highest standards of integrity, responsible behavior, and ethical conduct in professional activities” [4]. There are, without a doubt, risks undertaken in the process of designing such technology, but with the benefits far outweighing the risks, we find it to be worthwhile.

References

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