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Improved Power System for Radiello-Covering Device

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IMPROVED POWER SYSTEM FOR RADIELLO-COVERING DEVICE

Our project is a power generation, storage, and distribution system that is going to be used to power the operation of a Radiello-Covering device that will be used for atmospheric data collection for WashU research. Our goal was to be able to leave the covering device in the field for extended periods of time without human interaction while it is capturing and storing important atmospheric data. We used both wind and solar power to charge Li-ion batteries through a PCB board to deliver the necessary power to the device. We also altered the data collection code to minimize power draw during data collection.

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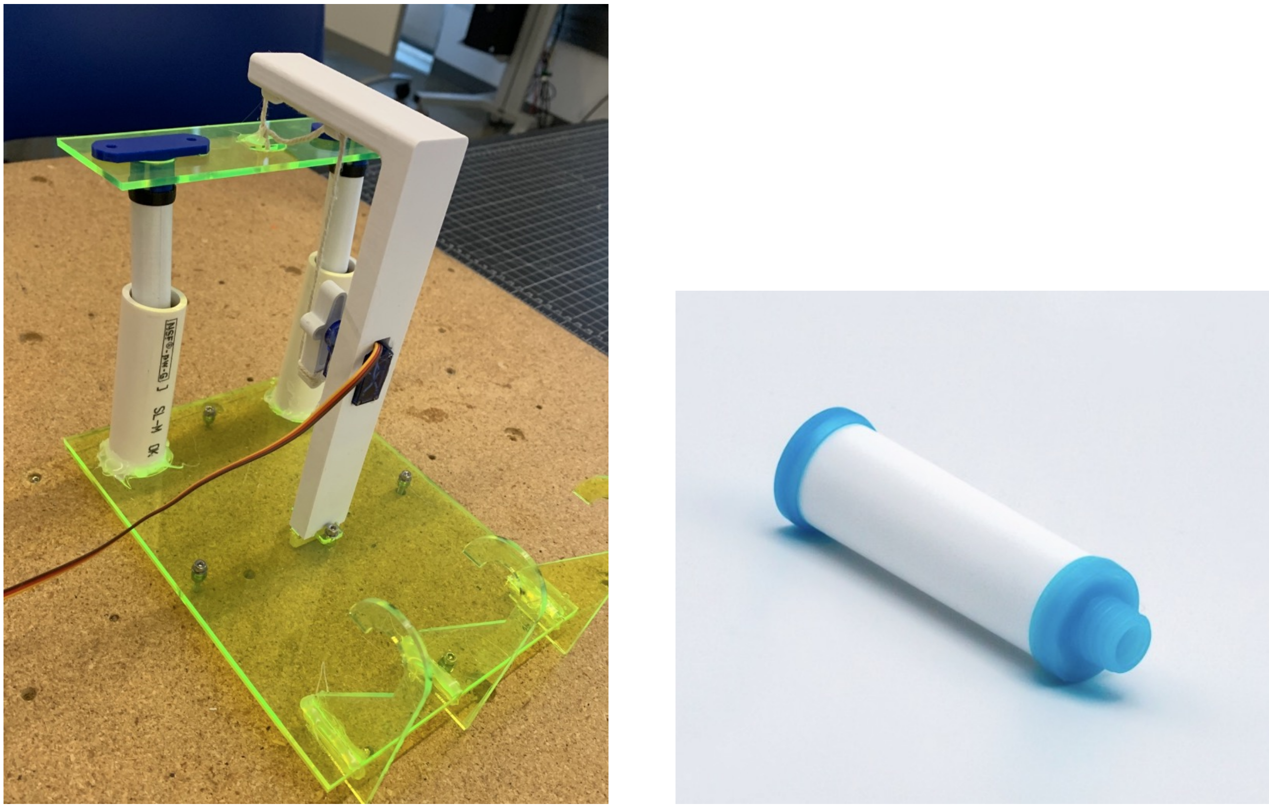
1 Introduction

Our project is a power generation, storage, and distribution system that is going to be used to power the operation of a Radiello-Covering device that will be used for atmospheric data collection for WashU research. Figure 1a shows a prototype of a Radiello-Covering device that was developed during the Fall 2023 semester of WashU's Multidisciplinary Design & Prototyping (MEMS 312) course. The Radiello atmospheric sampler that is being covered is shown in Figure 1b.



(a) Radiello-covering device from MEMS 312.

(b) Radiello chemical sampler

Figure 1: PRadiello-Covering device and Radiello atmospheric sampler.

Our goal is to be able to leave the covering device in the field for extended periods of time without human interaction while it is capturing and storing important atmospheric data. As seen in Figure 1a, the Radiello is being covered and uncovered via a contraption that uses a servo motor to raise and lower an atmospheric shield over the sampler. This motor is controlled with a Pololu A-Star mini board that has other data logging components in it. All of these components use electricity while functioning. The goal is for the prototype to last for more than two weeks in the field with no human interaction. When preliminary tests were done with a singular battery pack and a solar panel, the electronics components only stayed charged for about 5 days before dying. To solve this, we implemented both a recharging component for the batteries and are utilizing a battery with more capacity. The power draw of the prototype was also decreased by adding a sleep function that turns off many components when not in use. The current prototype will last for about 20 days if it were not charged at all during that time. Wind and solar power will be used to recharge the Li-ion batteries, so the batteries should have power for months. On a sunny day, it will take about 15 hours for the solar panel to fully recharge the batteries.

2 Problem Understanding

2.1 Existing Devices

We have looked into devices that already exist that are similar to what we are trying to do. We are hoping to use existing solar panels that deliver consistent low voltage and plan on modifying an existing vertical wind turbine to cater to our specific needs

2.1.1 Existing Charging Module #1: Adafruit Solar Lithium Ion Charger

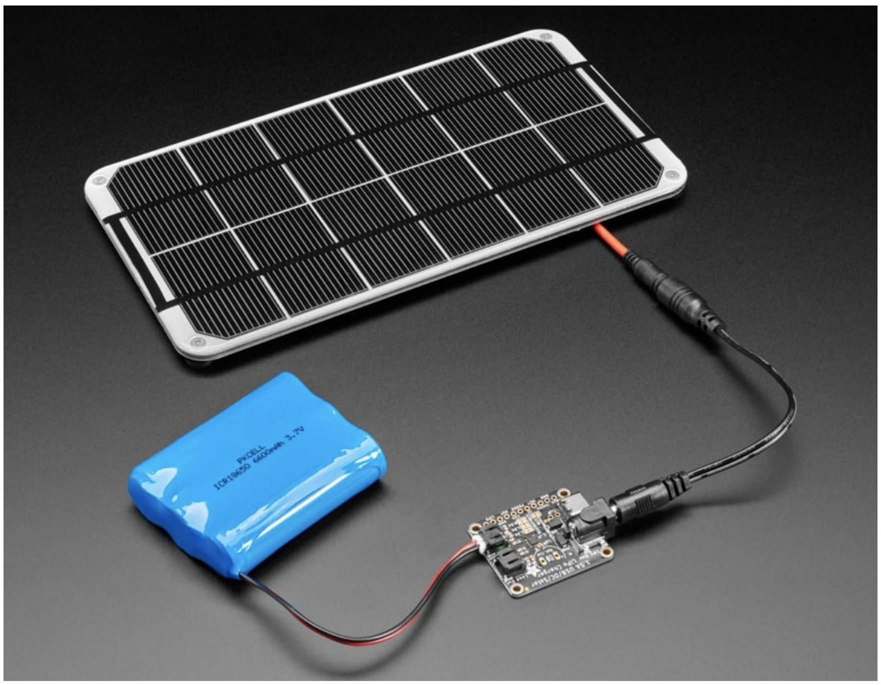


Figure 2: Adafruit Universal USB/DC/Solar Lithium Ion/Polymer Charger (Source: Adafruit.com)

Link: https://www.adafruit.com/product/4755
Description: This solar lithium ion battery charger is a device that delivers something very similar to what we are already looking for in our final design. The device offers a 5V solar panel as well as a power managing board that will assess the amount of power entering the board and disperse it either to a lithium ion battery or directly to the RCD. The main concern with this option is the uncertainty of solar power generation and its inability to generate power during non-sunlit hours of the day.

2.1.2 Existing Charging Module #2: DFRobot Solar Power Manager

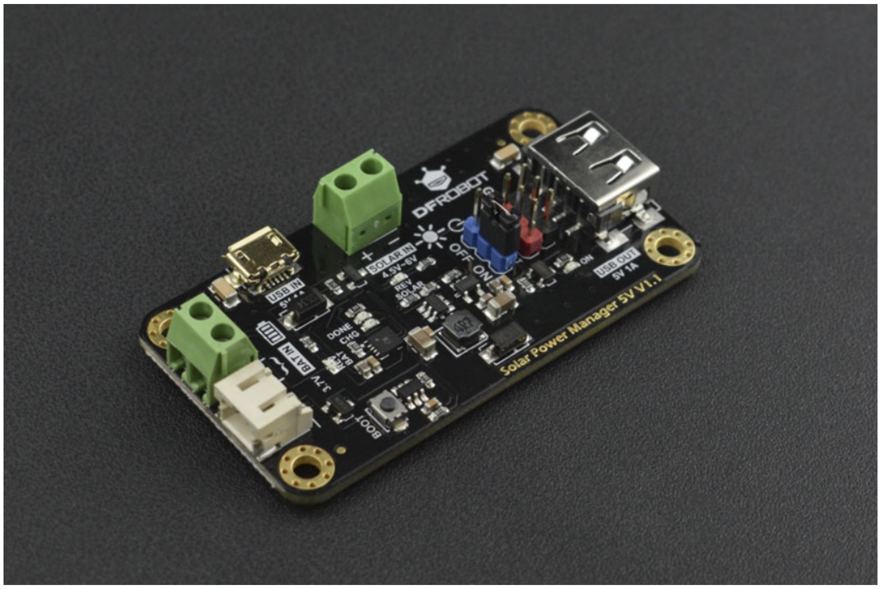


Figure 3: DFRobot Solar Power Manager 5V (Source: dfrobot.com

Link: https://www.dfrobot.com/product-1712.html
Description: The DFRobot Solar Power Manager is designed for dealing with power developed from small scale renewable energy source for DIY projects. It is made to be specifically a solar power manager, able to take in between 4.5-6V. This board allows for the plug-in of a 3.7V rechargable Li battery and can output 5V via USB plugin, making it a very useful design for our application. The main concern with this option is that it has a very small voltage input range of only 1.5V. This makes it difficult for it to be charged via wind energy as there is a lot of variability in the voltage being produced by a wind energy system.

2.1.3 Existing Power Source #1: Solar Phone Charger

Figure 4: Anker SOLIX 30W Foldable Solar Panel (Source: Anker.com)

Link: https://www.anker.com/products/a24261a1?variant=42656753549462
Description: The Anker fold-able solar panel is an on-the-go charging port that is able to provide 30W charging for multiple portable devices. The device is weather resistant and easy to carry. This particular item is too expensive for our budget and we feel that we can get a cheaper model because we do not need to be able to pack our panel up very small and transport it frequently after setup.

2.1.4 Existing Power Source #2: Portable Solar Panel

Figure 5: Nomad 7 Solar Panel (Source: Goalzero.com)

Link: https://goalzero.com/products/nomad-7-solar-panel
Description: The Nomad 7 Solar panel is a lightweight and portable solar panel that is designed for use while camping or backpacking. The weatherproof solar panel outputs 7W of power and is perfect for charging small electronics such as phones and power banks. This device is a great example of an effective solar power capturer but is too large and expensive for our desired application.

2.1.5 Existing Power Source #3: Wind Powered Phone Charger

Figure 6: Shine Turbine (Source: Shine.com)

Link: https://shineturbine.com/products/shineturbine
Description: The Shine turbine is a portable wind turbine that is capable of providing enough power to charge a phone or other personal electronic item. The turbine is lightweight and fold-able to allow for use while camping. It provides up to 40W of power and is capable of working in wind speeds ranging from 8-28mph. This device is a good baseline wind power generator but is too expensive for our current project. We would also like to be able to harness wind from any direction, making a vertical axis wind turbine a more desirable option for our use-case.

2.1.6 Existing Power Source #4: Mini Wind Generator

Figure 7: Mini Wind Generator (Source: Amazon.com)

Link: https://shineturbine.com/products/shineturbine
Description: The mini turbine shown in Figure 7 is a portable wind generator designed by Phoncoo to charge a phone. The device outputs a regulated to 5V. The device is a good base for our purposes but would struggle to output sufficient the amounts of power that we are looking for during high wind conditions. The generator can also only capture wind power from one direction, limiting its power generation capability and its application in our design.

2.2 User Needs

Below is a list of important features of our power system based on answers we received from our clients. We were then able to put together a system's needs and assign them a numerical value of importance for our product. This process is to increase the effectiveness of our design in the field.

2.2.1 Customer Interview

First Interview

Interviewees: Yan He
Location: Zoom Meeting
Date: Septemberst, 2023
Setting: This was a Zoom call between Dr. Potter and Yan He that took place after an initial conversation about the project. The interview took about half an hour and was recorded for later use.

Interview Notes:
Does the speed of the wind matter when taking data? Are the sensors close enough to the site so that air can reach it in low wind conditions?

- The closest sampling site in 300 meters away and the furthest is 100 meters. The air should be able to get from the site to the closer Radiello in a fairly short amount of time but will take longer to reach the further Radiello. It would be beneficial to have some sort of way of only testing when the wind is strong enough to reach the Radiellos.

Have you found any damage to the current samplers from animals?

- We have not had any damage yet to the current samplers but when more things are added to the sampling device setup they may be more interested. We are mostly worried about squirrels.

Do the shelters need to be waterproof? Do the Radiellos need to remain dry?

- The Radiellos do need to remain dry and the sampling device should be able to work in all weather conditions. There is a maximum of four Radiellos in each setup to make sure that they remain dry even in windy and rainy conditions. The chemical samplers are measured in the lab by placing them in water and measuring what is transferred into the water. If the samplers get wet from rain, they will give an under estimated concentration of pollutants in their results because the rain has already washed some chemicals from the bodies.

Can we set up with a longer board if we need more space to attach components to?

- We have more boards in the lab so we would be able to supply a larger board if that is needed to fit all of the parts.

Second Interview

Interviewees: Dr. Jay Turner and Yan He
Location: Jubel 330, Washington University in St. Louis, Danforth Campus
Date: February 1st, 2024
Setting: We looked over some of the past prototypes and mockups. We discussed important factors and various details of the project. The interview was conducted in person and took about an hour.

Interview Notes:
Do you sample throughout the year or only during certain months?

– The project will require sampling during cold months. Yan would like to sample every month for 2 weeks at a time. She plans to go to the project location once to set up the sampling stations. After the initial set up, she ideally won't return to the sampling stations. Local residents would collect and exchange the Radiello samplers and SD cards. The samples and SD cards would then be shipped back to Yan for analysis.

Would you prefer to leave the gray plastic housing installed, or would you prefer to remove all of them from the field?

– Doesn't matter.

Were there any previous prototypes that stood out to you in particular?

– Dr. Turner emphasized the importance of simplicity as the project location is hours away. It will be difficult to make repairs so a robust device with a minimum of moving parts is ideal.

2.2.2 Interpreted User Needs

After conducting the interviews with Dr. Jay Turner and Yan He, the following needs were determined.

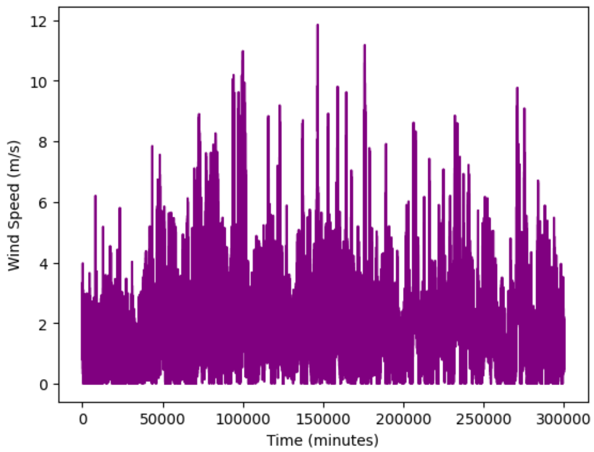
Table 1: Interpreted Project Needs

Need Number	Need	Importance
1	The equipment is easy to transport	4
2	The equipment is durable	5
3	The equipment is easy to set up	3
4	The equipment is reliable	5
5	The equipment is waterproofed	5
6	The equipment is visually appealing	1
7	The equipment is snow-resistant	2
8	The equipment is inexpensive	3

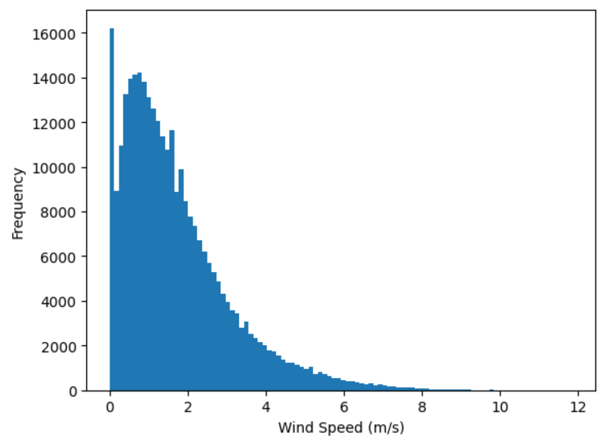
From this table it is easy to see what is most important and least important to the user. The most important things are that the equipment is durable, reliably supplies power, and generally weatherproofed. The less important aspects of the technology is that it is visually appealing and particularly easy to transport.

2.3 Wind Data Processing

After the interview with Dr. Jay Turner and Yan He, Yan sent wind data that was collected at their sites so we could analyze the data. This data was crucial to developing the constraints of this project and understanding how the wind turbines would perform. An Excel file with environmental data from July 26, 2022, to July 10, 2023. The data was logged every minute and included useful information such as temperature, wind direction, and wind speed. When analyzing the data, we only looked at the first 208 days because there was a period of time that the wind direction and speed was not measured. For the first 208 days, the mean wind speed was 1.71 m/s, with a median wind speed of 1.37 m/s, and a standard deviation of 1.39 m/s. The wind speed varied from 0 to 11.85 m/s, but the wind speed was only greater than 6 m/s for short periods of time. Figure 8a shows how the wind speed changed with time, and figure 8b shows the frequency of each wind speed. The wind speed with the highest frequency was 0 m/s, which seems like it may have been due to an error in the data collection. This is because the rest of the wind speed data looks to be normal and follow a bell shaped curve.



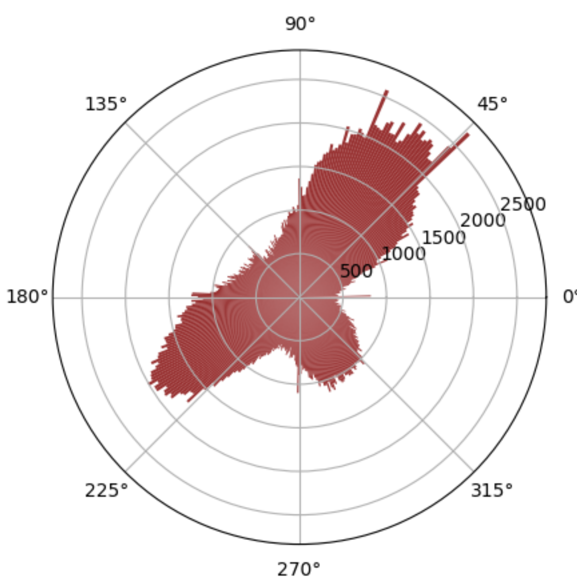
(a) Wind Speed from July 2022 - February 2023



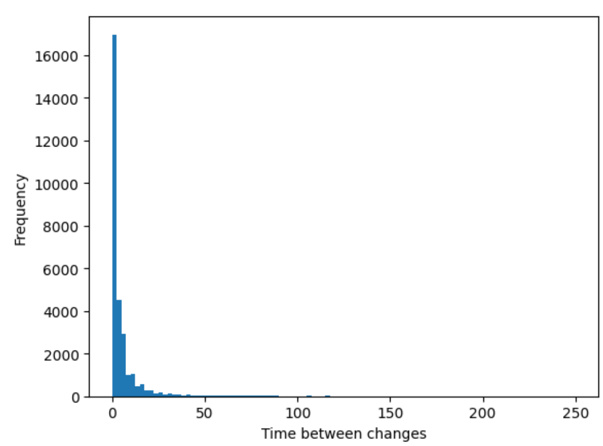
(b) Wind Speed Frequency from July 2022 - February 2023

The direction of the wind was also analyzed to understand what direction the wind typically goes and how often the radiello device would need to cover and uncover the sensors. Figure 9a shows a radial histogram of the wind direction, which shows that the wind typically coming or going from the northeast at 45°.

By tracking how the wind direction changed over time, we determined how often the device would need to cover and uncover the radiellos. The mean time between changes was 9.58 minutes, with a standard deviation of 70.94 minutes. The reason that the standard deviation was so high is because there were quite a few times when the wind direction did not change for over 24 hours. Figure 9b shows a histogram of how frequently the radiellos will need to be covered and uncovered. The data for this is very skewed because the time between changes can change drastically.



(a) Wind Direction Frequency from July 2022 - February 2023



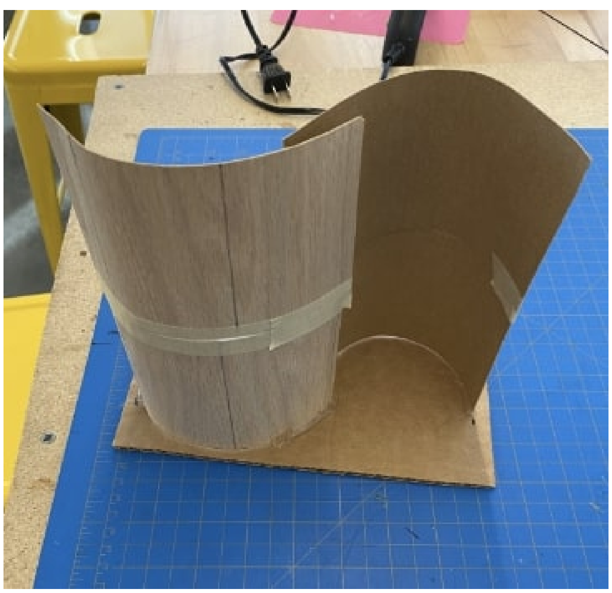
(b) Times Between Covering and Uncovering the Radiello

3 Concept Generation

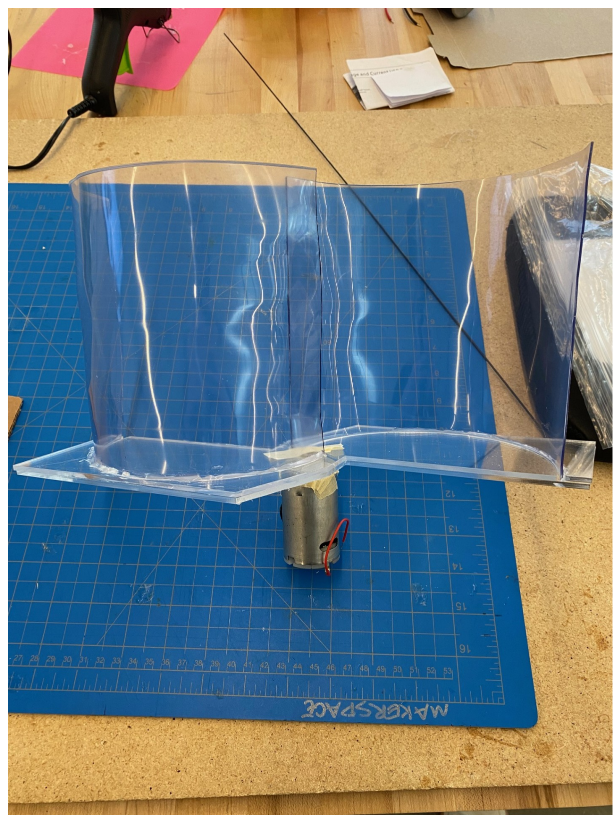
3.1 Mockup Prototype

A large amount of research into the most effective types of turbines was done before mockup creation. We were mostly looking into a vertical axis wind turbine design as it would be able to capture all directions of wind flow and would be effective in low wind environments. It would also allow the data logging equipment to know when a sufficient amount of wind was blowing to activate the data logging equipment and take effective data.

We created two different mockup designs for the wind turbine design and learned quite a bit from each of them. The first mockup design that we made was a Savonius bucket shaped turbine made from cardboard and a second version made from a clear, rigid, plastic material. These two mockups are shown below in Figures 10a and 10b, respectively. This design was very effective at producing large amounts of torque at high wing speeds but struggled in low wind environments. We did learn from this prototype that the weight of the turbine plays a significant role in the amount of power produced in low wind conditions. If we could create a turbine to maximize wind swept area while minimizing weight, we would be able to produce power with the slightest of breezes.



(a) Cardboard double-bucket turbine.



(b) Acrylic double-bucket turbine.

Figure 10: Double-bucket turbine mockups.

The second mockup that we made was for a four sided flap turbine, pictured in Figure 11. The idea is that the turbine wings are able to rotate 90 degrees to make it aerodynamic on one side of the vertical axis and able to catch wind gusts and provide torque on the other. The mockup was made with a wooden down that had holes drilled into it where a bent wire passed through. The wire had two plastic sheets taped to it on either end. These plastic sheets were attached so that they were able to rotate 90 degrees to fully capture wind on one end while minimizing drag on the other. This design did not work perfectly, but was very beneficial in what it taught us about vertical turbines. One of the most important things that we learned is that although increasing the turbine's width and horizontal distance from the vertical axis should provide more torque, it also provides significantly more drag and drastically decreases efficiency in low wind scenarios. From this we learned that it is more beneficial to expand our turbine vertically to maximize power generation, especially in relatively low wind environments.

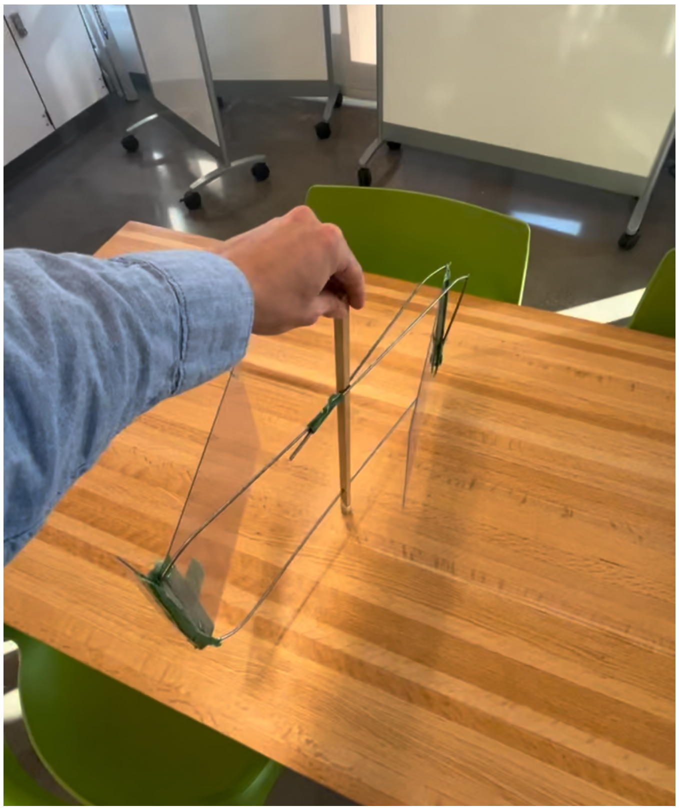


Figure 11: Flap turbine mockup.

3.2 Alternative Design Concepts for Turbine

3.2.1 Concept #1: The Prop

Figure 12: Prototype of propeller turbine.

Description: This concept is based on the propeller of an RC plane. The design works well in high winds but struggles to get started when wind speeds are low. In addition, the design only harnesses power from wind in a very narrow range of directions as it is a horizontal axis turbine and not a vertical design.

3.2.2 Concept #2: The Double Bucket

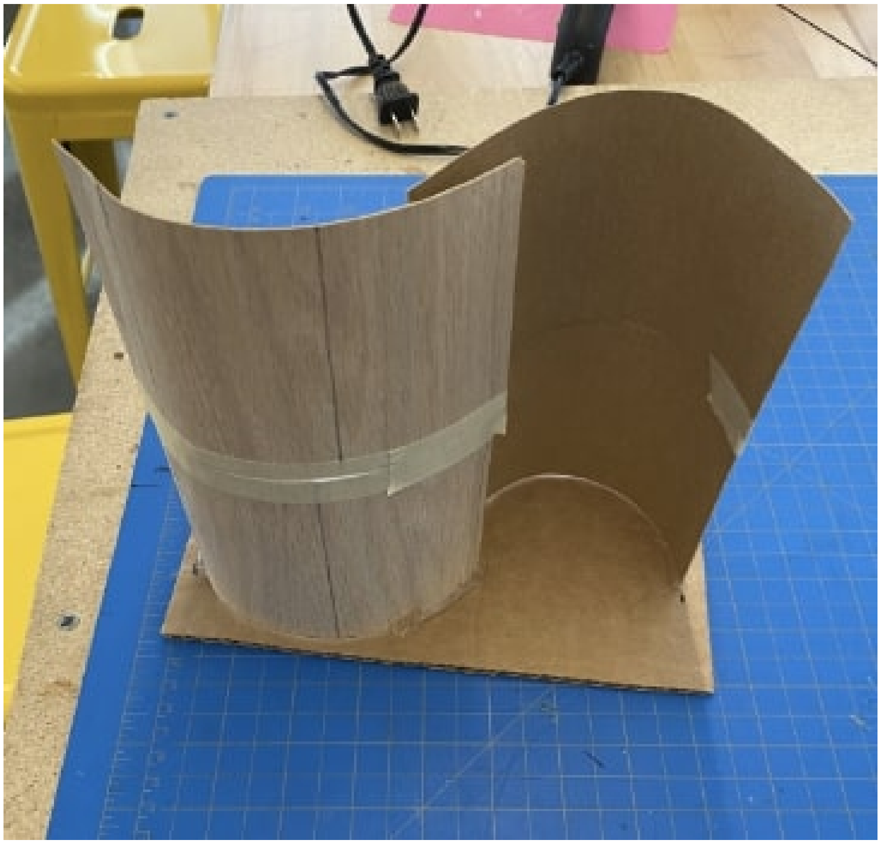


Figure 13: Prototype of double bucket turbine in cardboard.

Description: Prototype #2 uses an "S"-shape approach similar to that of the Savonius turbine. There is a center axis that the buckets rotate around, turning the shaft of a motor. This allows for the turbine to generate power from all wind directions but causes it to struggle in low wind environments.

3.2.3 Concept #3: The Acrylic Double Bucket

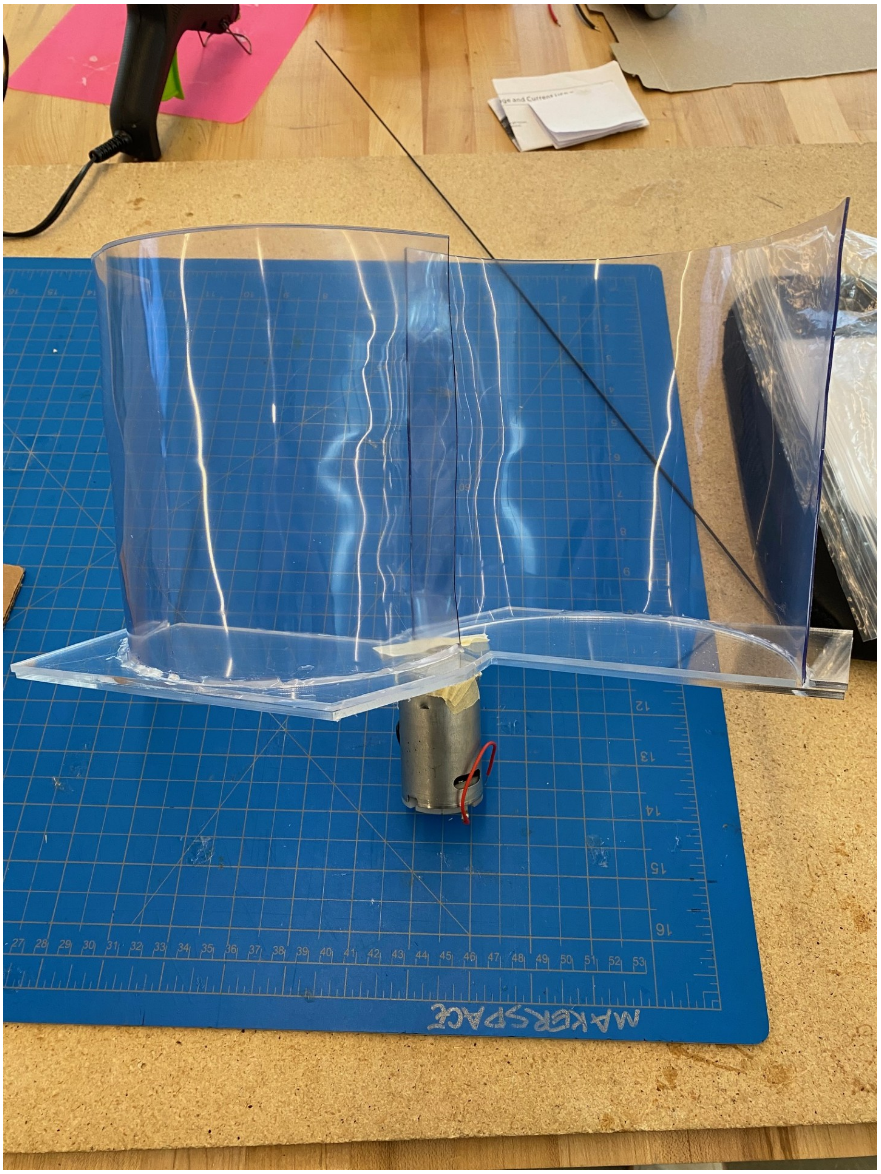


Figure 14: Prototype of double bucket turbine in acrylic.

Description: Prototype #3 uses an "S"-shape approach similar to that of the Savonius turbine. The is a center axis that the buckets rotate around, turning the shaft of a motor. This allows for the turbine to generate power from all wind directions, but it struggles to start in low wind environments. This is because in low wind conditions, the rotational force produced by the open side of the bucket is not enough to overpower the opposite rotational force acting on the closed side of the bucket, preventing it from gathering any rotational speed.

This model is different from prototype #2 because it was constructed by bending thin sheets of acrylic and setting the shape with a heat gun. Top build this, three acrylic molds were laser-cut and the thin sheets were bent to fit into the molds. The sheets and molds were heated until the acrylic sheets became flexible, then were cooled into the bucket shapes. This base of this turbine was very heavy compared to the thin buckets, so this model rotated relatively slowly in the wind.

3.2.4 Concept #4: Darrieus Turbine

Design Link: VAWT - SuperColin

Figure 15: Prototype of Darrieus turbine.

Description: Concept #4 is a lift-type turbine that uses lift force to create torque around the center axis. This means that it has a higher start-up torque but is not very variable once it gets up to speed. This makes it less susceptible to wind gusts and give it a more constant voltage output. Although having a relatively consistent voltage output is ideal for our application, the Darrieus turbine requires too much wind to start for it to make much sense to use in our final design.

3.2.5 Concept #5: Flappy Turb

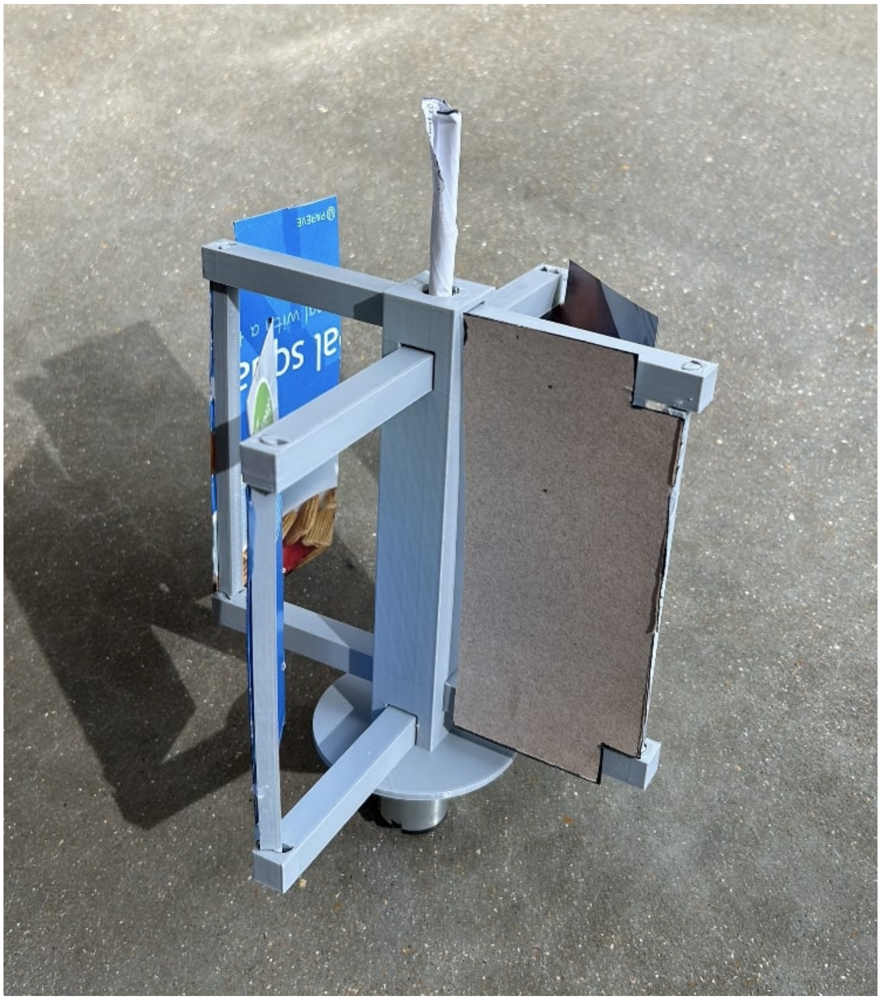


Figure 16: Prototype of flap turbine.

Description: Concept #5 uses rotating flaps that are able to capture wind energy by being perpendicular to the wind direction on one side of the rotating axis and then flipping to be parallel to the wind direction when it reaches the other side of the vertical axis. This maximizes the drag force on the side causing the turbine to rotate and minimizes the drag force in the direction opposing rotation. This turbine was effective at capturing low wind speeds, but very quickly reached a maximum rotation speed and did not produce enough voltage.

3.2.6 Concept #6: Flap Turbine Circle

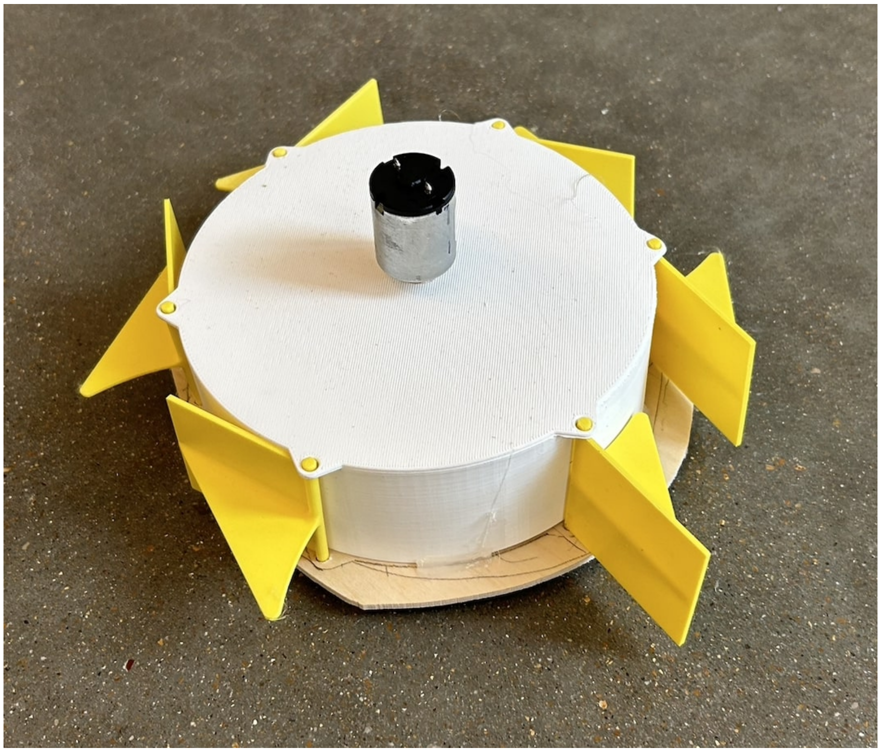


Figure 17: Prototype of circlular flap turbine.

Description: Concept #6 uses rotating flaps in a similar way to concept 4. This concept is based around a cylindrical base that rotates around a center axis due to the wind energy captures by hinged flaps around the perimeter of the turbine. This turbine was not effective as its wind capture area was not very large, and it was relatively heavy with components that did not capture energy.

3.2.7 Concept #7: Ugrinsky Turbine

Design Link: https://www.thingiverse.com/thing:6236759

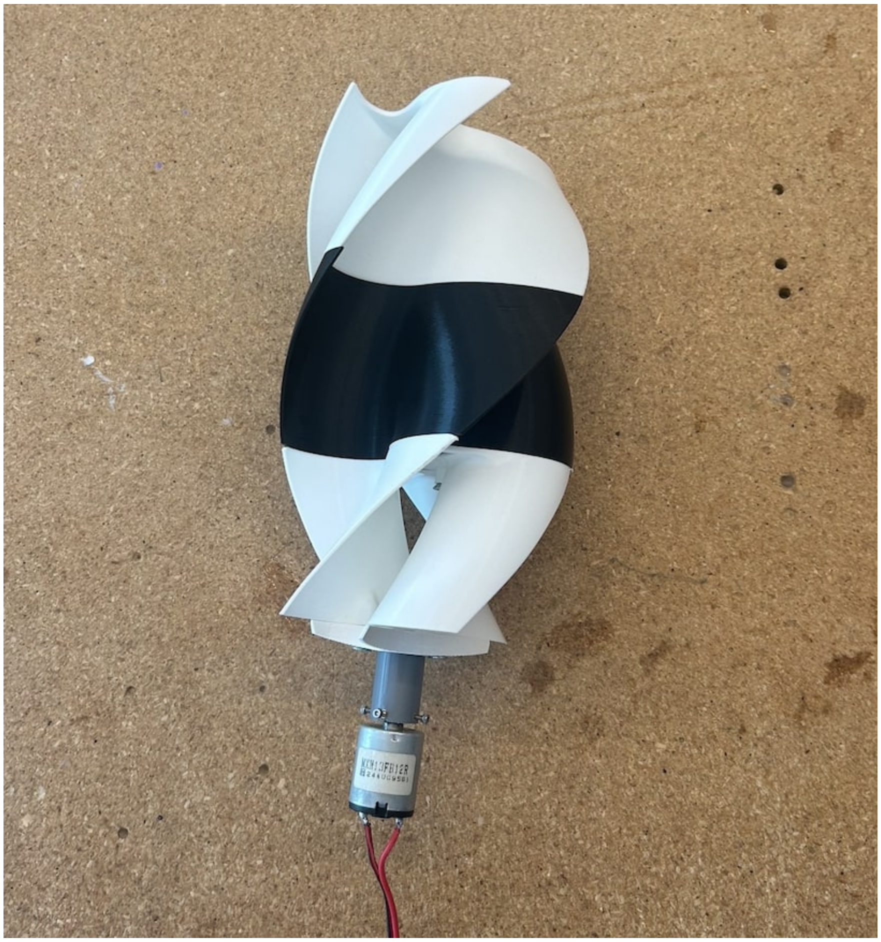


Figure 18: Prototype of Ugrinsky turbine.

Description: Concept #7 uses the Ugrinsky turbine design, which is a slight modification of the more common Savonius turbine. This turbine is designed with two blades that run parallel to each other in a concentric spiral. This drag type turbine performs well in low wind speeds and can effectively pump out power during low wind conditions. This design was found on Youtube (Link: https://www.youtube.com/watch?v=e7ymRJA4qVY&t=147s) and was created by Robert Murray-Smith. It is a modular design that allows for experimentation with how different numbers of layers affect energy production.

3.2.8 Concept #8: Lightweight Fabric Turbine

Figure 19: Prototype of lightweight green fabric turbine.

Description: Concept #8 is a similar design to the Ugrinsky turbine in Concept #7 but is instead made of out a very lightweight fabric held in place by long, thing, lightweight rods. Although this was the lightest of the designs and had a very large wind-swept area, it struggled to hold its shape and effectively capture wind, falling apart in higher wind speeds.

4 Concept Selection

4.1 Power Testing

All the turbines created were tested in the WashU Jubel Makerspace using a box fan, a multimeter, and a yard stick. The turbines were tested for voltage output using two different motors at 18 inches and 36 inches using all three fan speeds. A picture of the testing setup is showing below in Figure 20. The wind speeds were measured at each distance and fan setting using a digital anemometer, shown below in Figure 21. The wind speeds are recorded below in Table 2. The results from the power tests from 18 inches and 36 inches away from the fan are shown in Tables 3 and 4, respectively.

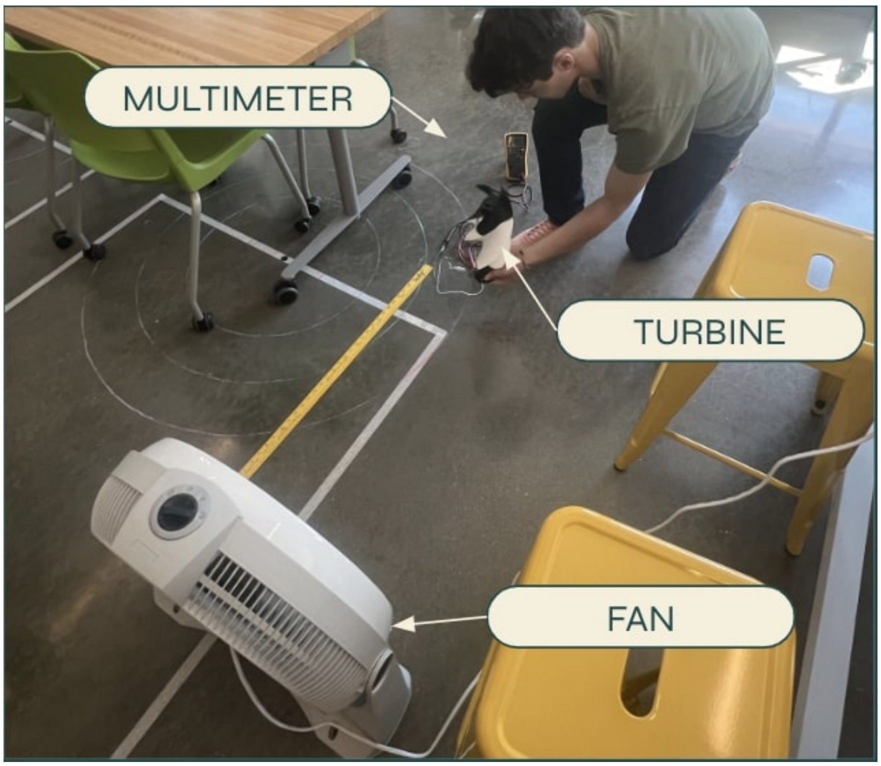


Figure 20: Testing setup showing turbine, fan, and multimeter.

Figure 21: HP-866B Anemometer used to find wind speeds.

Table 2: Wind Speed Data

		Fan Setting		
		1	2	3
Distance (in)	18	3.4	4.4	5.1
	36	3.2	3.6	4.1
	72	2.1	2.6	2.9
		Wind Speed (m/s)		

Table 3: Voltage Output at 18 Inches from Turbine Models at Different Fan Settings

		Fan Setting		
		1	2	3
Turbine	**Motor**	11.5	15	19
Plane Prop	Medium	0	0	19
Acrylic Bucket	Medium	0.7	1.1	1.5
Foam Spinner	Small	0.2	0.2	0.25
Plane Prop	Small	3.65	4.5	5.6
Flap turbine 2 flaps (10% infill)	Small	0.31	0.4	0.51
Flap turbine 4 flaps (10% infill)	Small	0.34	0.44	0.55
Flap turbine 2 flaps (5% infill)	Small	0.31	0.43	0.5
Flap turbine 4 flaps (5% infill)	Small	0.36	0.45	0.55
Flap turbine extended horizontally 2 flaps (10% infill)	Medium	0.8	1.1	1.4
Flap turbine extended horizontally 2 flaps (5% infill)	Medium	0.25	0.26	0.26
Ugrinsky four layers	Small	1.5	1.2	1.5
Ugrinsky four layers	Medium	1.7	1.81	4.8
Ugrinsky three layers	Small	1.4	1.8	1.9
Ugrinsky three layers	Medium	4.4	6.7	7.8
Ugrinsky two layers	Small	0.97	1.5	1.6
Ugrinsky two layers	Medium	0	2.47	4.2
Ugrinsky one layer	Small	0.85	1.3	1.6
Ugrinsky one layer	Medium	0	0	0
		Voltage (V)		

Table 4: Voltage Output at 36 Inches from Turbine Models at Different Fan Settings

		Fan Setting		
Turbine	**Motor**	1	2	3
Plane Prop	Medium	8	10	14
Acrylic Bucket	Medium	0	0	0
Foam Spinner	Small	0	0.6	0.93
Plane Prop	Small	0.15	0.22	0.27
Flap turbine 2 flaps (10% infill)	Small	3	3.6	4.2
Flap turbine 4 flaps (10% infill)	Small	0.22	0.36	0.4
Flap turbine 2 flaps (5% infill)	Small	0.3	0.39	0.44
Flap turbine 4 flaps (5% infill)	Small	0.29	0.36	0.45
Flap turbine extended horizontally 2 flaps (10% infill)	Medium	0.3	0.4	0.44
Flap turbine extended horizontally 2 flaps (5% infill)	Medium	0.65	0.89	1.2
Ugrinsky four layers	Small	0.59	1.1	1.4
Ugrinsky four layers	Medium	0.73	1.4	2.8
Ugrinsky three layers	Small	1.2	1.5	1.6
Ugrinsky three layers	Medium	3.3	5.5	6.3
Ugrinsky two layers	Small	0.81	1.3	1.4
Ugrinsky two layers	Medium	0	0	1.7
Ugrinsky one layer	Small	0.61	1.1	1.2
Ugrinsky one layer	Medium	0	0	0
		Voltge (V)		

In Tables 3 and 4, the motor labeled ”small” is a MXN12FB12F motor that was found in the basement of Jolley on WashU’s campus. The motor labeled ”medium” is a Pacific Sky Power DC Project Motor Generator that was purchased from Amazon. These motors are shown below in Figures 22a and 22b.

(a) "Small" motor used during testing.

(b) "Medium" motor used during testing.

Figure 22: Small and Medium Motors

An additional motor (shown in Figure 23) was tried, but it was not used because it was difficult to turn compared to the other motors. This motor was a modified stepper motor that had two bridges created with diodes and capacitors to maximize the power output from this generator. This motor charged the capacitors while it spun, which stabilized the output voltage from the motor.

To create this motor, a guide from Robert Murray-Smith was followed. He posted a video on his YouTube channel, All About Converting Stepper Motors To Generators, which showed the process of converting a stepper motor to a generator.

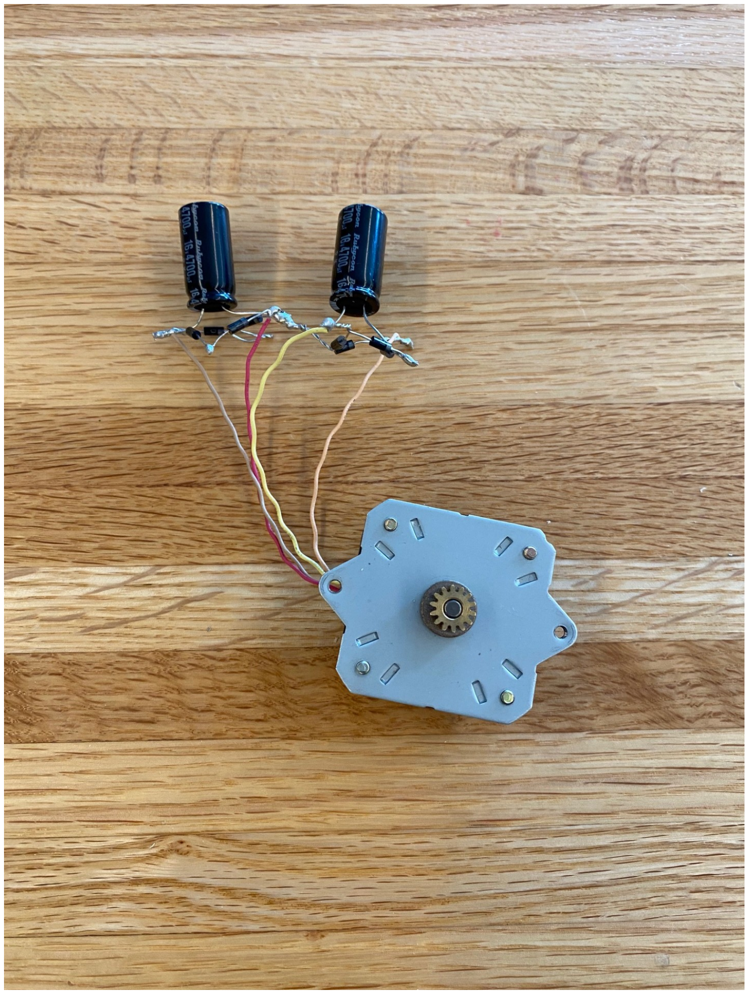


Figure 23: Modified stepper motor.

After completing our testing it was decided that the best design would be to use the smaller motor attached to the Ugrinsky turbine design with three layers. This design was the most consistent across all wind speeds and was able to effectively produce power in all conditions. Also, by using a step-up transformer, we were capable of boosting the low voltage to 5V. The power managing board that is being used takes in a minimum voltage of 5V to charge the battery. The Regulator Voltage Boost Converter Board 0.9-5V to 5V, pictured in Figure 24, was used to step-up the output voltage from between 1-2V to 5V.

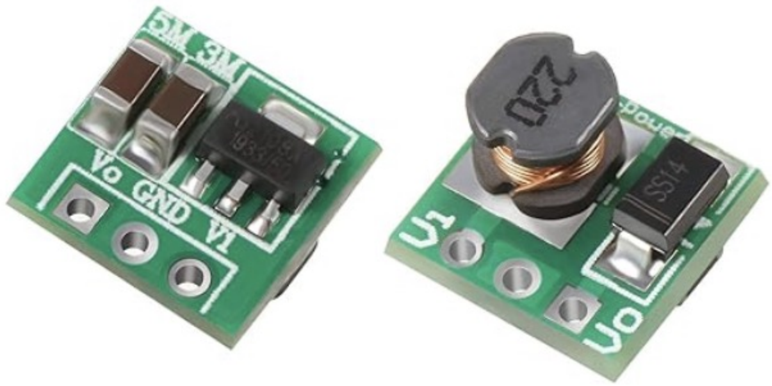


Figure 24: Step-up voltage transformer.

5 Concept Embodiment

5.1 Initial Embodiment

Figure 25 shows the initial prototype that was used by Dr. Potter when investigating this project.

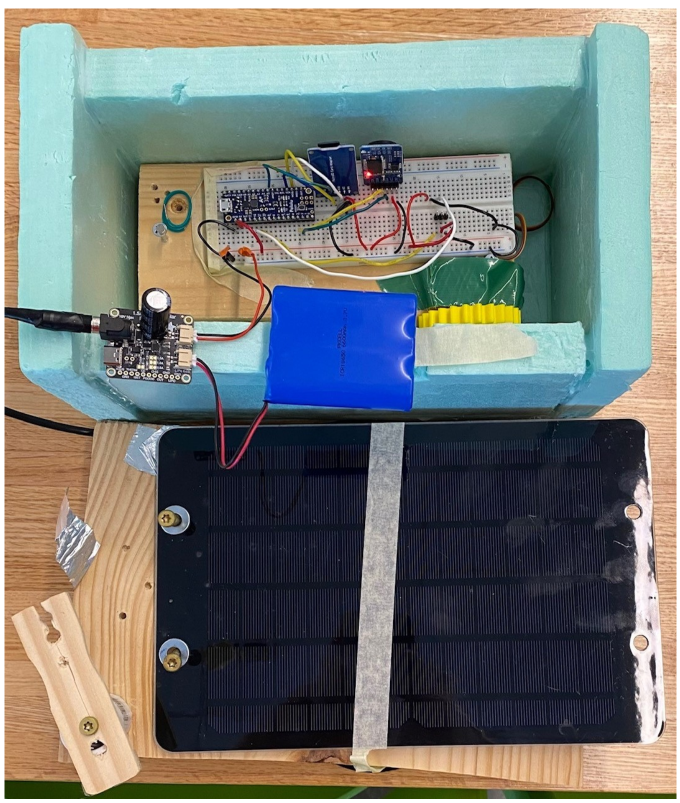


Figure 25: Initial Prototype from Dr. Potter

The final design will be put into the field attached to a 2x10" piece of wood that is hanging on a freestanding metal pole. The field setup is shown below in Figures 26a and 26b.

(a) Field setup 1. (b) Field setup 2.

Figure 26: Field setups of Radiellos.

Prototype Performance Goals:

Our prototype performance goals were established after an interview with Dr. Jay Turner and Yan He. In order for our project to achieve its purpose, we hope that it can meet the performance goals listed below:

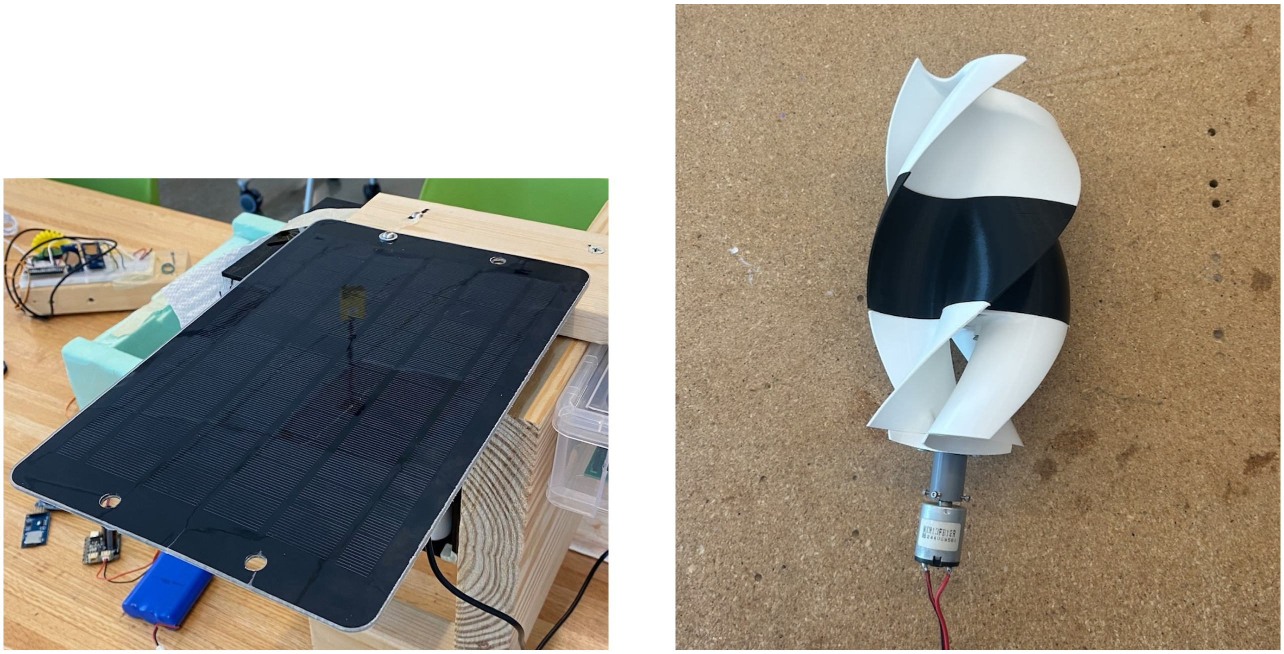
- The device must be able to stay powered for at least two weeks.
- The radiellos must be uncovered if the wind direction is $\pm 22.5^o$ from a desired direction.
- The project must be easy to assemble in the field without any external training.

If we are able to meet these prototype performance goals in our final prototype, we would consider our design project to be on the right track toward what we wanted at the beginning of the semester.

5.2 Battery Charging

Two 18650 Li-ion batteries are being used to power the electronics, so they must be continuously charged. We are harnessing wind and solar energy to keep the batteries charged at all time. There are three components that all work together to charge the batteries: power generation, management, and storage.

- **Power Generation**: To generate power, a solar panel and a wind turbine are both being used. Both components are being used in parallel, so they each charge their own battery. This is because both components generate different amounts of power at different times, so it is easier to keep them separate. The solar panel being used outputs 5W at 6V with an efficiency of 22%. The wind turbine being used has the voltage regulated to 5V. Figure 27 shows the solar panel and wind turbine being used.



(a) 6V 5W Solar Panel (b) Wind Turbine

Figure 27: Solar panel and wind turbine being used.

- **Power Management**: To manage and control the flow of energy, an Adafruit Universal Charger is being used. This power manager accepts input power from 5-10V and outputs no more than 4.4V. Additionally, this board will charge a Li-ion 18650 battery with load sharing between the input power and the battery [1]. However, this power manager only accepts one input, so two of these manager must be used in parallel, with two battery packs. Figure 28 shows the power manager with a stabilization capacitor soldered on.

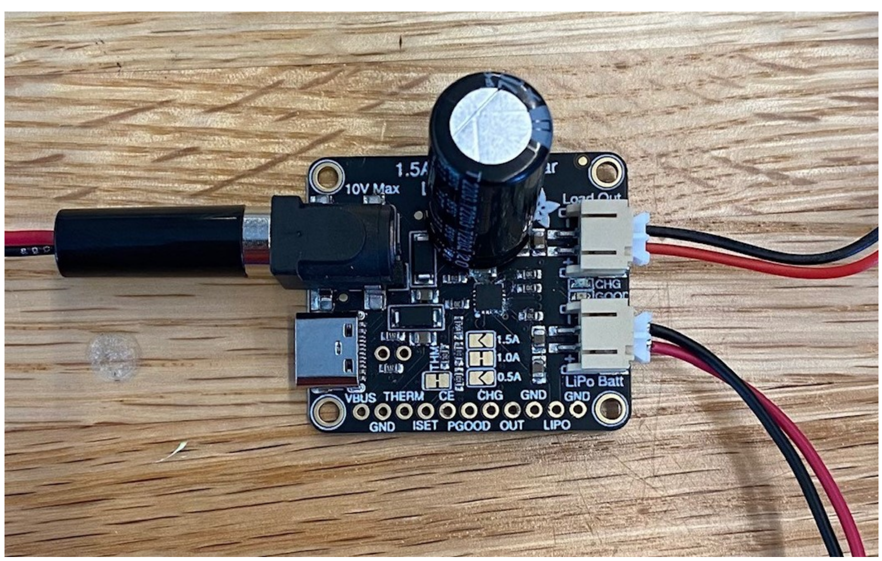


Figure 28: Adafruit Universal Charger

- **Power Storage**: For this project, 18650 Li-ion batteries were chosen for power storage. This is because they have a high capacity, small, and have a large operating temperature. Initially, three low-density cells were used in parallel to obtain 6600mAh per battery pack, but these cells were upgraded to obtain a capacity of 10500mAh per battery pack. These cells have a discharge operating temperature of -20-60°C and a charge operating temperature of 0-45°C. This means that these battery packs will be able to provide power at all times of the year. Figure 29 shows the battery packs being used in this project.

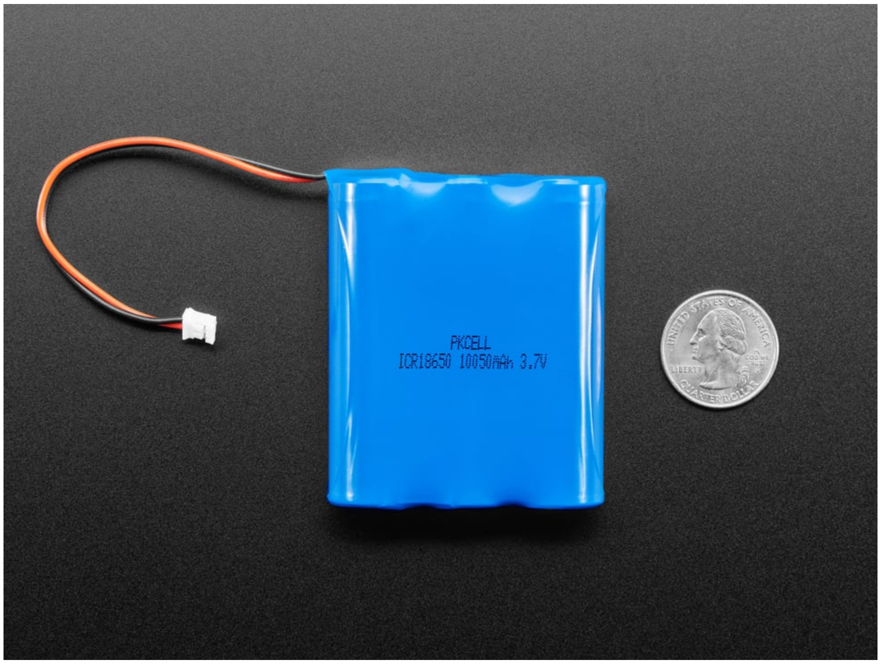


Figure 29: 18650 Li-ion Battery Pack

Figure 30 shows a schematic of how the solar panel and wind turbine will be connected to each other. Each power generator will have its own Adafruit Universal Charger and 18650 Li-ion battery pack. The outputs of both Adafruit Universal Chargers will be connected in parallel to the battery terminals of the Pololu A-Star mini.

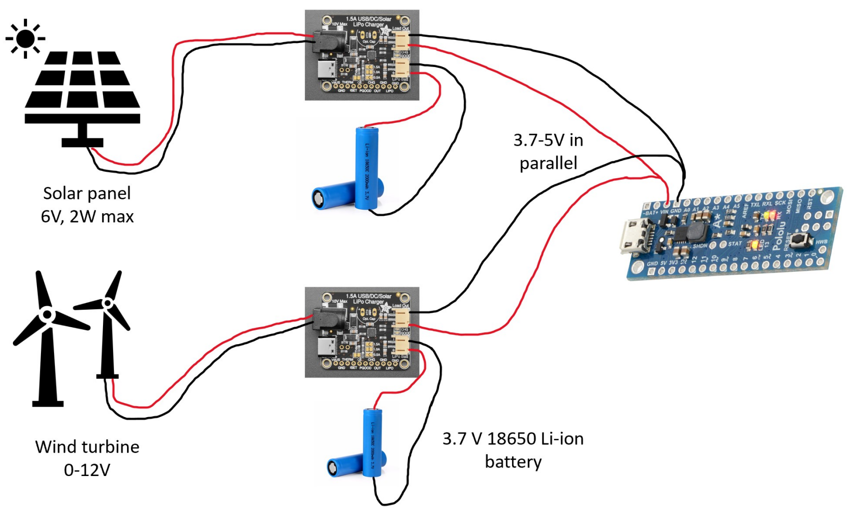
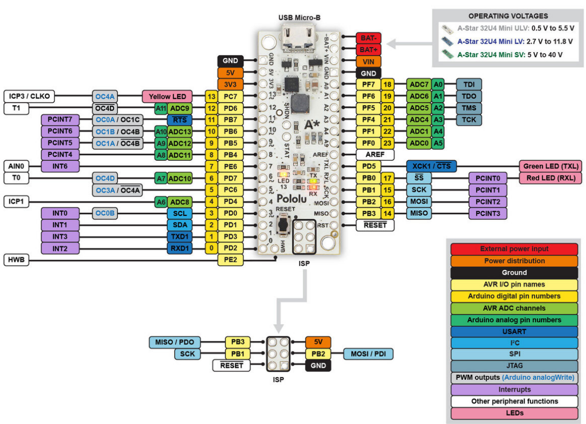


Figure 30: Schematic of Battery Charging

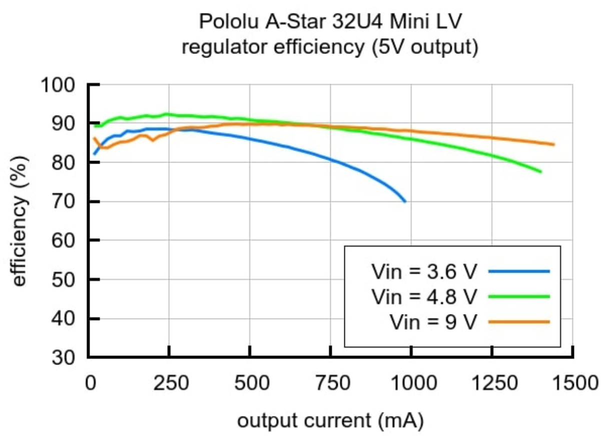
5.3 Radiello Control

The purpose of this device is to collect measurements of wind direction to cover and uncover the radiello sensors based on the wind direction. The data collected is also saved to an SD card so that it can be analyzed to determine when and how long the radiello devices are exposed to the air. To perform these tasks, five components are needed:

- **Microcontroller**: For this project, a Pololu A-Star 32U4 Mini LV was chosen as the microcontroller. This is because it has a variable range of input voltages from 2.7-11V, so it can be powered by a 3.7V Li-ion 18650 battery. Additionally, it has 7 PWM outputs and 12 analog inputs that can be used on this board, which is crucial when working with multiple components. There is an internal voltage regulator that outputs to 5V, so even though the board will be powered at about 3.7V, it can easily power the 5V servo motor. Figure 31 shows the pinout and regulator efficiencies of the Pololu A-Star [2].



(a) Pololu A-Star Pinout Diagram

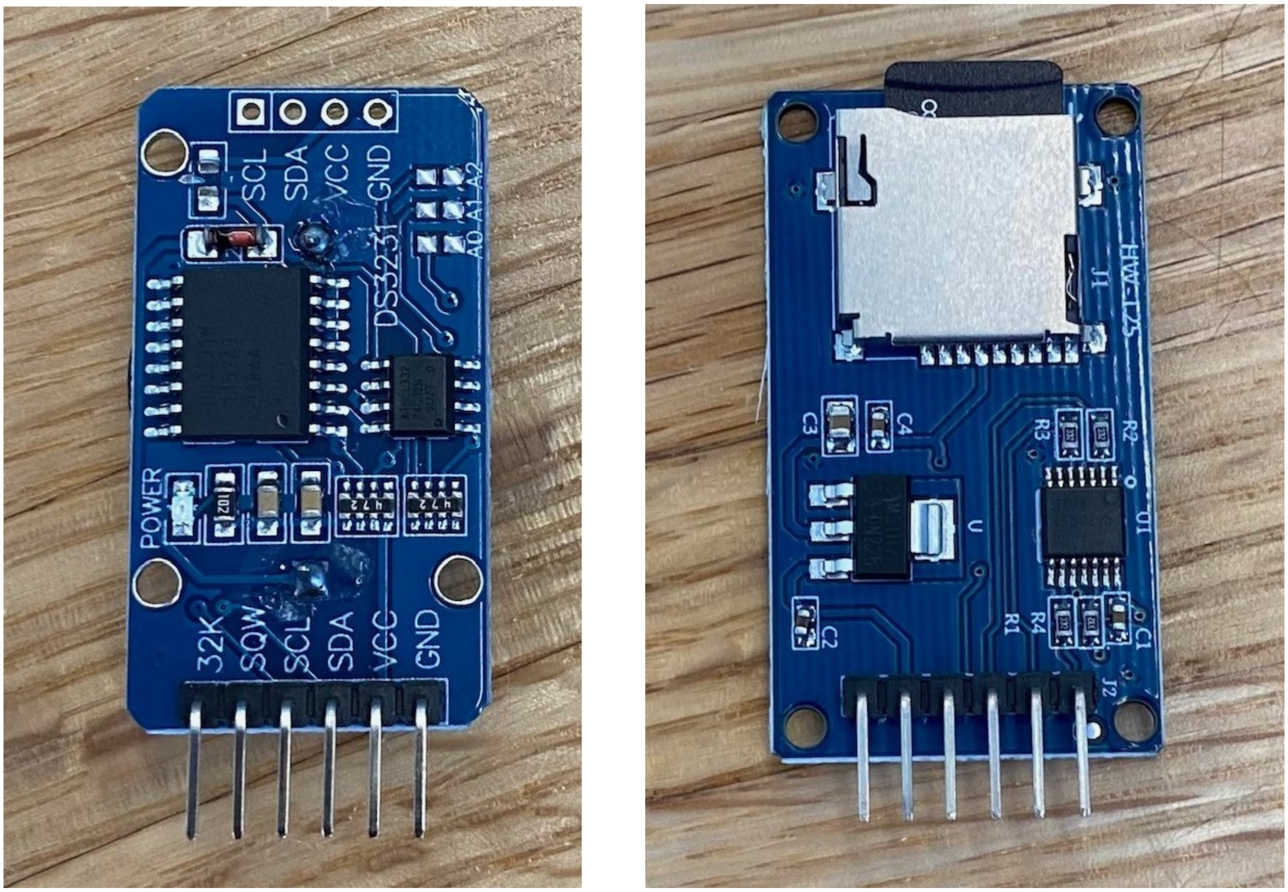


(b) Pololu A-Star Regulator Efficiency

Figure 31: Pololu A-Star 32U4 Mini LV

- **Real-Time Clock**: The DS3231 AT24C32 Real-Time Clock Module allows the device to keep track of the time and date. This is important because it provides timekeeping to the project, so it is easy to determine when the radiello devices were covered and uncovered. This module has an annual error of 1 minute per year and will account for leap years until 2100.

- **SD Card Reader**: The HW-125 SD Card Reader allows the device to write data logging to a micro SD card, so data can be stored for later processing. This board uses an SPI interface and uses a 3.3V voltage regulator.



(a) DS3231 AT24C32 Real-Time Clock Module

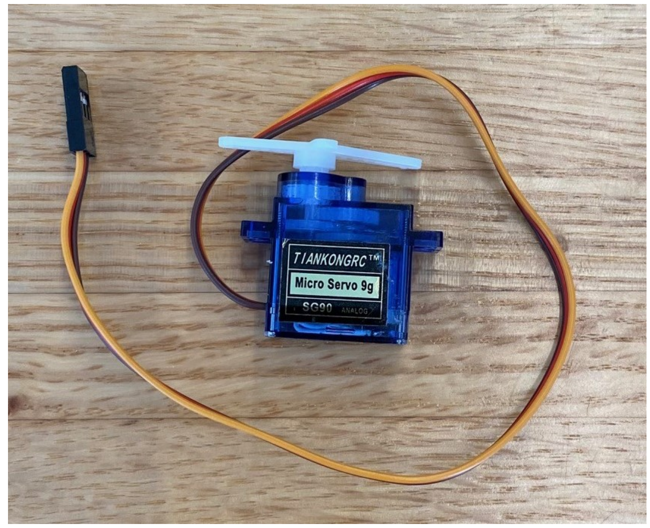
(b) HW-125 SD Card Reader

Figure 32: Real-Time Clock and SD Card Reader

- **Hall Effect Sensor**: The 49e 24280 Hall Effect Sensor is a linear hall effect sensor that outputs a voltage based on a presence of a magnetic field. This hall effect sensor is being powered by 5V, and the output voltage can be read by an analog pin on the microcontroller. This analog reading is used to determine if the wind vane is pointing in the correct direction.

- **Servo Motor**: The Tiankongrc 9g Micro Servo is a small servo that can powered at 5V and controller with an analog PWM signal. This servo has a no load current of 60mA and has a no load speed of 111.1 rpm. In reality, this servo will have a load applied to it, so it will likely move slower and draw more power than it would with no load. However, by analyzing historical wind data, it was determined that the servo would only need to rotate every 10 minutes, on average. Additionally, the servo will be detached for the majority of its time in the field, and the quiescent current is only 5mA [3].

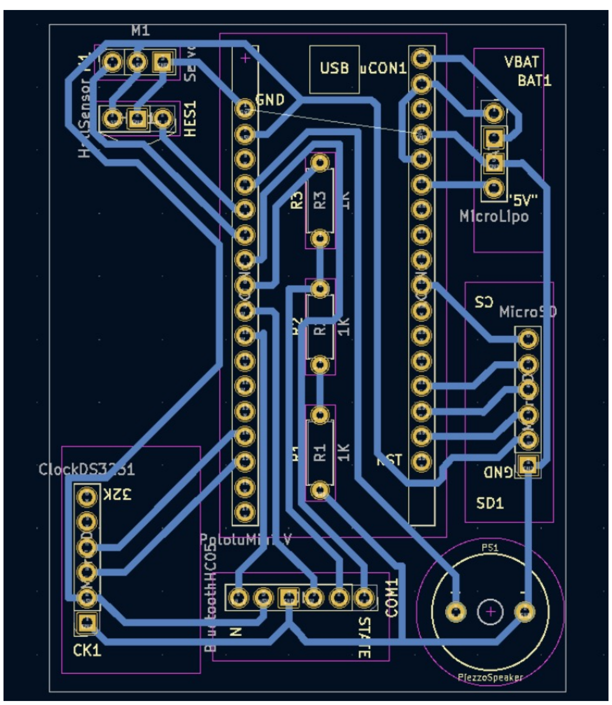
(a) 49e 24280 Hall Effect Sensor [4]



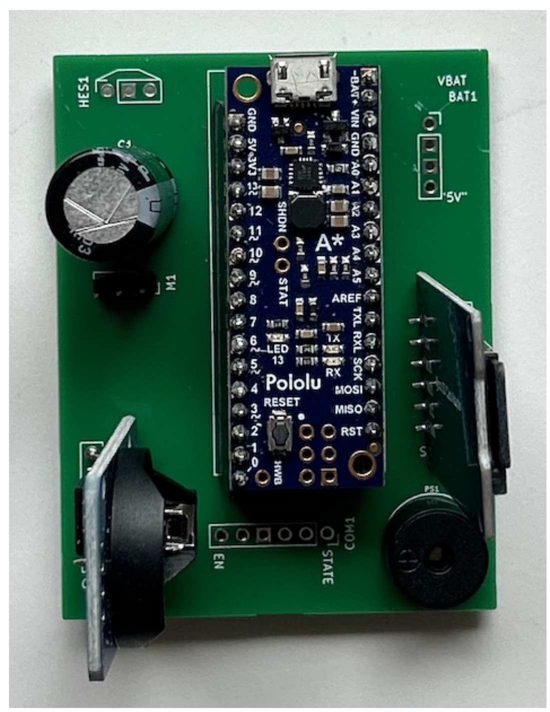
(b) Tiankongrc 9g Micro Servo

Figure 33: Hall Effect Sensor and Micro Servo

- **PCB Board**: A PCB board was designed by Dr. Potter so that all the components could be soldered into a smaller board than a regular breadboard. The PCB board layout was created in KiCAD and made through JLCPCB. The PCB board layout is shown below in Figure 34a, and the traces for the components are shown on this layout. The final PCB board with components soldered can be seen in Figure 34b.



(a) PCB board layout.



(b) Created PCB board.

Figure 34: PCB board.

The final wiring schematic with all components is shown in Figure 35.

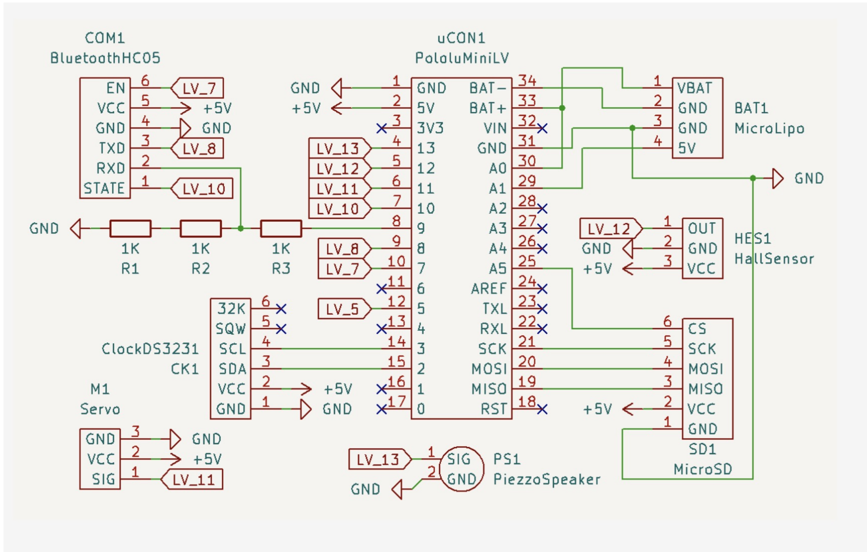


Figure 35: Wiring schematic of all components.

5.3.1 Radiello Control Software

This software contains the main code for controlling a radiello covering device with a servo motor, hall effect sensor, and SD card.

Pin Configuration:

- servoPin: Pin number for controlling the servo motor.
- hallPin: Pin number for reading the hall effect sensor.
- groundPin: Pin number for the ground connection of the voltage divider.
- voltagePin: Pin number for reading the voltage divider output.
- microSDpin: Pin number for the MicroSD card chip select.
- SDApin: Pin number for the serial DATA pin.
- SCLpin: Pin number for the serial CLOCK pin.

Constants

- periodWrite: Time interval between serial and SD card writes in seconds.
- periodServo: Time interval between servo repositions in seconds.
- hallNeutral: No-magnet sensor reading (0 to 1023).
- hallThresh: Threshold for uncovering radiello when far away from neutral.

Variables

- hallValue: Current hall effect sensor reading.
- servoPos: Current position of the servo motor (0 is covered, 180 is uncovered).

- dataString: String to hold data for writing to the SD card.
- prevWriteMillis: Time of the previous write operation in milliseconds.
- prevServoMillis: Time of the previous servo move operation in milliseconds.
- totalSec: Total time the device has been on in seconds.
- uncoveredSec: Total time the radiello has been uncovered in seconds.

Objects

- SERVO: Servo object for controlling the servo motor.
- RTC: DS3231 object for real-time clock functionality.

Functions

- position_servo_motor(): Controls the servo motor based on the hall effect sensor reading.
- initialize_sd(): Checks for the presence of an SD card and initializes it if found.
- toSleep(): Puts the microcontroller to sleep for 8 seconds to save power.
- check_capacity(): Calculates the battery capacity percentage based on the voltage level.
- check_data(): Checks the data file size and creates a new file if the current file is too large.
- write_to_sd(): Writes data to the SD card.
- setup(): Initializes pin modes, starts communications, and initializes objects.
- loop(): Main loop function that performs tasks, puts the microcontroller to sleep, and repeats.

5.3.2 Control Loop

Figure 36 shows the functions that the microcontroller will perform in a loop. After setup, the microcontroller will take measurements of the hall effect sensor and battery voltage to record in a data file. The data file will also include the time, date, and amount of time the radiello has been uncovered. After writing that data to the SD card, the reading from the hall effect sensor will be used to determine which direction the wind is coming from. If the wind is a 45 degree window of the desired wind direction, the radiellos will be uncovered. If the wind is not coming from the desired direction, the radiellos will be covered up. Finally, the microcontroller will go to sleep for 8 seconds before repeating this process again.

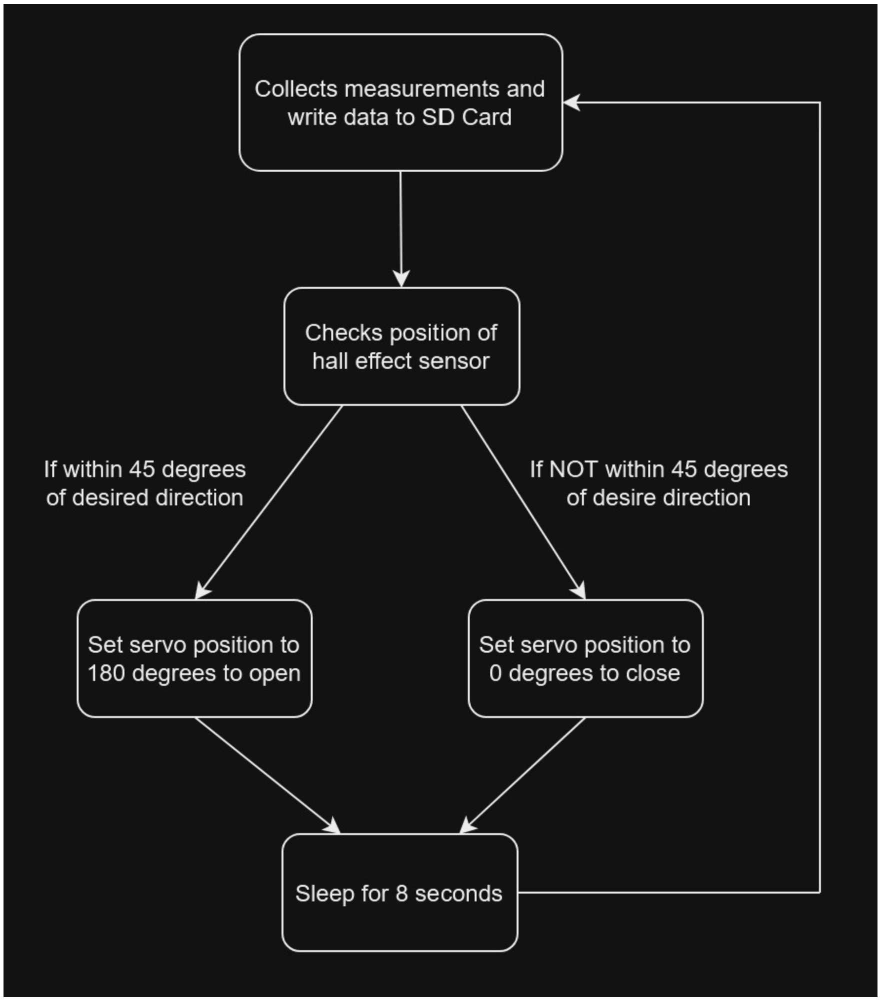


Figure 36: Radiello Control Loop

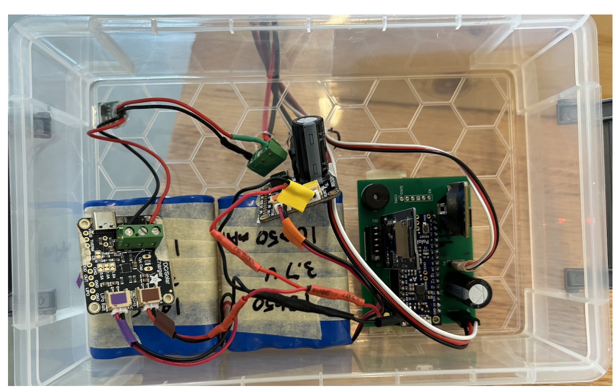
6 Final Prototype

The final prototype of the Radiello-Covering Device and the connected power generation and storage system is shown below in Figure 37.

Figure 37: Final prototype of device.

The final device has all components attached to a piece of wood that will be screwed into a board in the field to allow for easy setup and to keep all components in place. The electronics are stored in a pencil box that has a lid screwed into the bottom of the board. The electronics box is shown below in Figure 38a. The electronics box with all included components is pictured in Figure 38b.

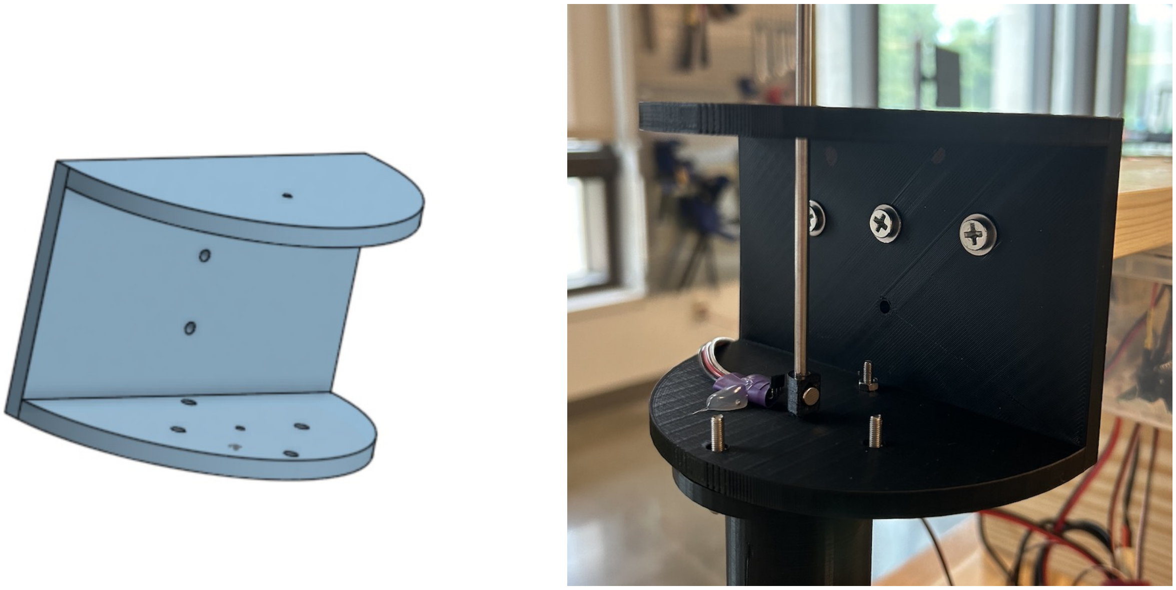
(a) Electronics box.



(b) Electronics box with included components.

Figure 38: Electronics box.

The wind turbine sticks out of the bottom of a 3D printed housing that was modeled using Onshape software. Screenshots of the CAD design and the actual printed version are shown below in Figures 39a and 39b, respectively..

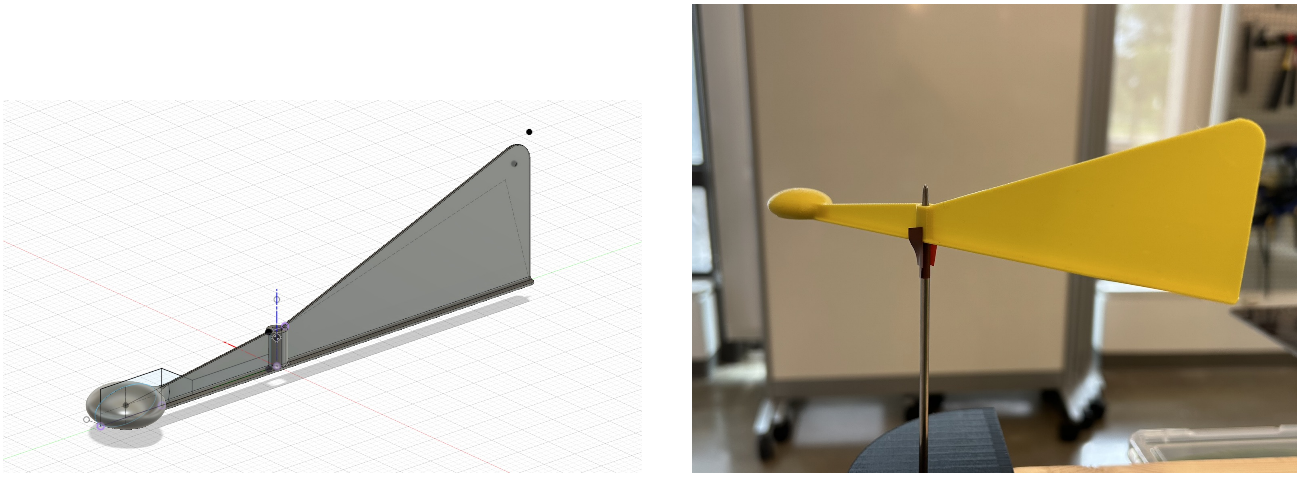


(a) Motor housing CAD screenshot.

(b) Motor housing 3D printed.

Figure 39: Motor housing.

By sticking the turbine out of the bottom of the prototype, we allowed for the wind vane to sit comfortably through the top to give accurate wind direction measurements that were relayed to the Polulu board via a hall effect sensor. The turbine coming out of the bottom of the housing also allowed us to prevent the motor and wiring from getting wet during rainy conditions. The wind vane top is attached to a sewing needle that is able to freely rotate within the hole in the motor housing. Wind vane topper designs were created in MEMS 312 during the fall semester of 2023 in Fusion360. One of the wind vane tops designed is shown below in Figure 40a. The final wind vane design that is being used in our prototype is also pictured below in Figure 40b.

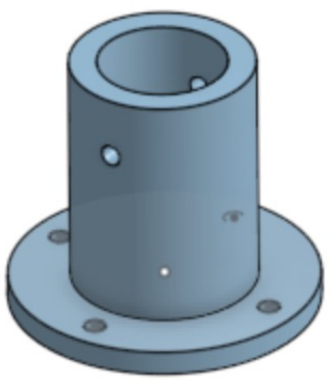


(a) Wind vane topper designed in MEMS 312.

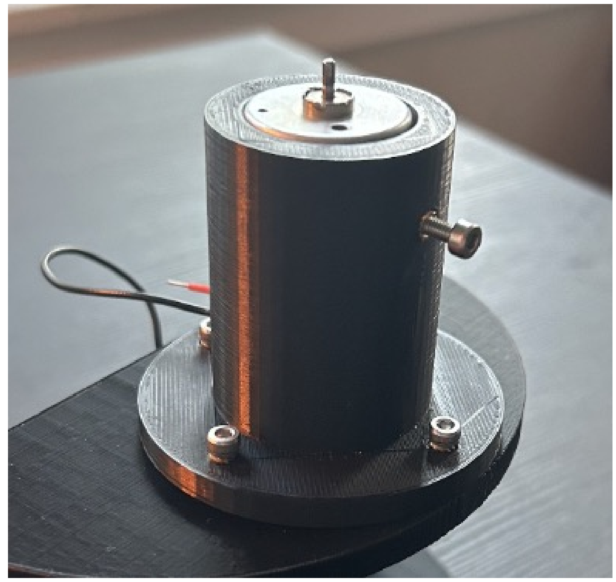
(b) Wind vane topper used in final prototype.

Figure 40: Wind vane.

The turbine is connected to the housing via a motor holder that was also designed in Onshape and printed in the Jubel Makerspace. There are also holes in the side of the motor holder to allow for a set screw to hold the motor in place while the turbine is hanging upside down. A screenshot of a CAD file for the motor holder and the printed motor holder can be seen below in Figures 41a and 41b, respectively.



(a) Motor holder CAD screenshot.

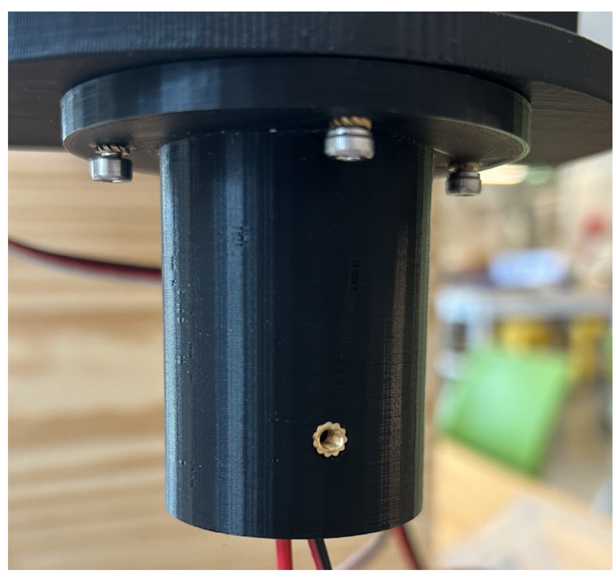


(b) Motor holder 3D printed with inserts.

Figure 41: Motor holder.

Inserts were melted into the housing and the motor holder in aligned holes to allow for the holder to be tightened to the bottom of the housing. The inserts used in the prototype are shown below in Figure 42a. The inserts can be seen soldered into the motor holder in Figure 42b.

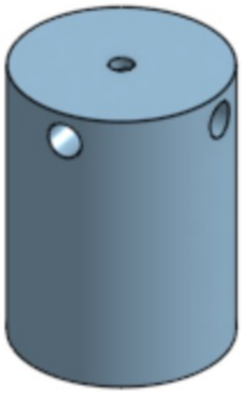
(a) Inserts used in prototype.



(b) Inserts soldered into motor holder of prototype.

Figure 42: Heat set inserts.

The turbine flaps were connected to the motor shaft through a 3D printed motor coupler that was also designed using Onshape software. The same inserts used in the motor holder were also used in the coupler to allow for the flaps to be securely tightened to the motor shaft. The CAD model and 3D printed version of the motor coupler can be found in Figures 43a and 43b, respectively.

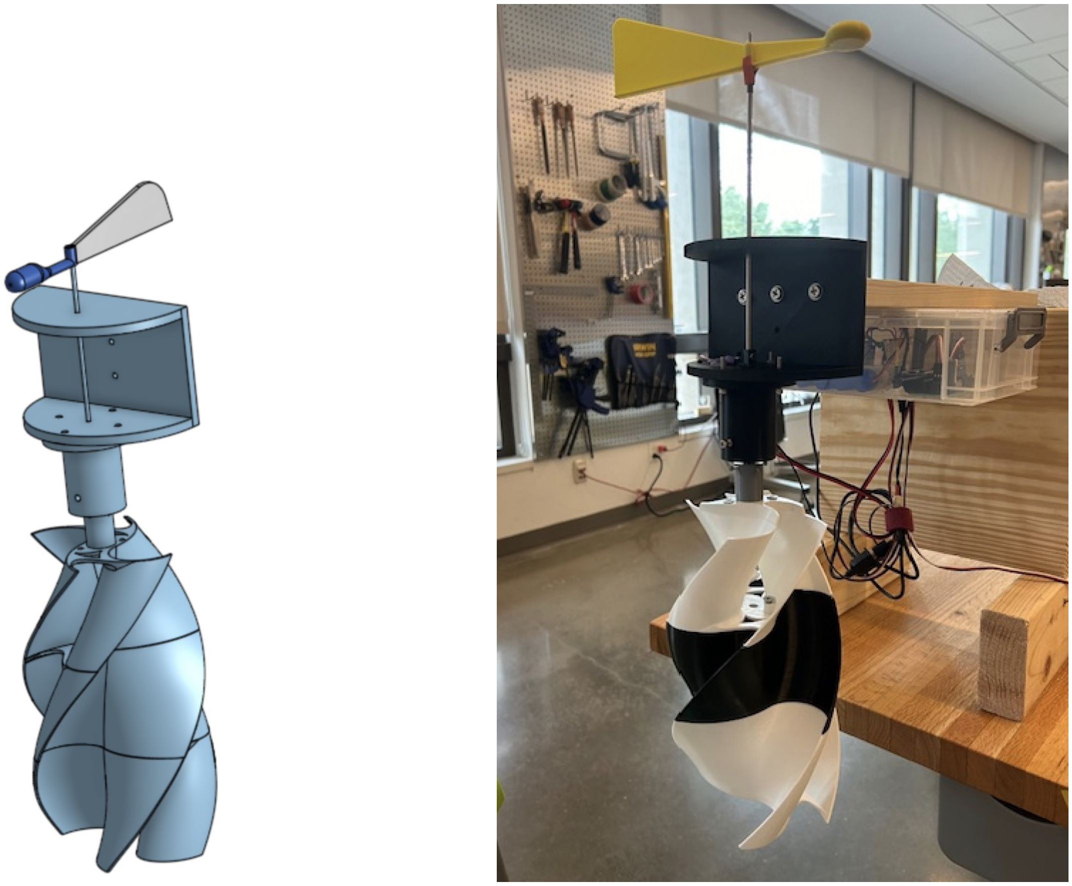


(a) Motor coupler CAD screenshot.

(b) Motor coupler 3D printed with inserts.

Figure 43: Motor couple.

As seen in Figure 37, the final design was attached to a piece of wood that is easily attachable to a piece of wood in the field. A final CAD assembly of the parts of the wind turbine and wind vane can be seen in Figure 44a. The final setup of the wind turbine and wind vane components of the prototype are shown fully assembled in Figure 44b.



(a) Final CAD assembly of wind turbine and wind vane.

(b) Final assembly of wind turbine and wind vane.

Figure 44: Final assembly.

6.1 Overview

The final prototype, with the implemented sleep code, solar and wind generators, and battery storage packs, should be able to last in the field for considerable amounts of time, meeting our most important customer need. With just the two battery packs and the sleep code implemented, the system is able to last for 480 hours (20 days). The solar panel was tested to completely charge its battery pack in about 52 hours during relatively sunny conditions. The wind turbine power output is much more variable but during windy conditions it should be able to produce enough power to keep the battery charge level. Combining these two charging sources will allow for the whole system to be left unattended for weeks at a time.

6.2 Installation

To install this device in the field, there are a few steps:

1. Place the device with all the components attached and screw into the 2x10 board (Figure 45). The device should be placed so the radiello housing is on one side of the board, and the electronics are on the other side. There are 2 pre-drilled holes that can be used to screw the device into the board.

Figure 45: Screwed in top board.

2. Turn the wind vane to face the direction from which you want to sample the wind (the rounded shape is the "front" of the wind vane).

3. Hold the wind vane in place and rotate the plastic magnet collar so that the magnet is facing the hall effect sensor. The hall effect sensor is the small black box that is glued to the wind vane housing. Figure 46 shows the correct position.

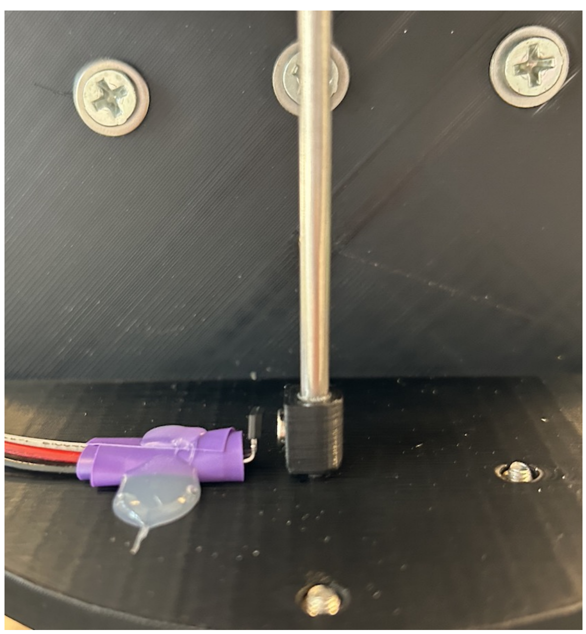


Figure 46: Wind vane collar lined up.

4. Open the flaps on the side of the clear box and plug-in the power managers to the batteries and microcontroller (Figure 47. There will be 4 connections, and each connection is color-coded (Figure 48a and 48b. After plugging these in, close the box and wait for the initialization sequence described in the next step.

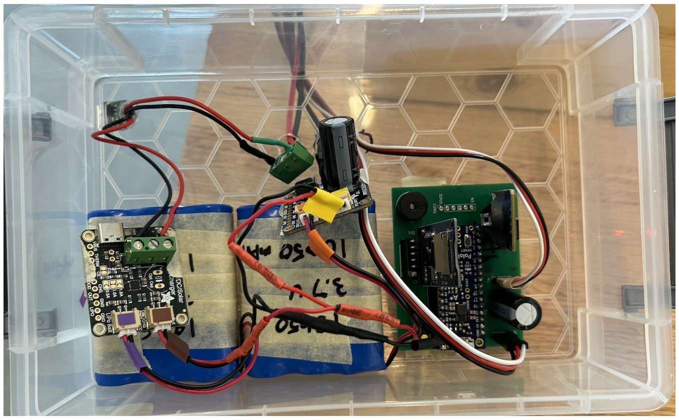
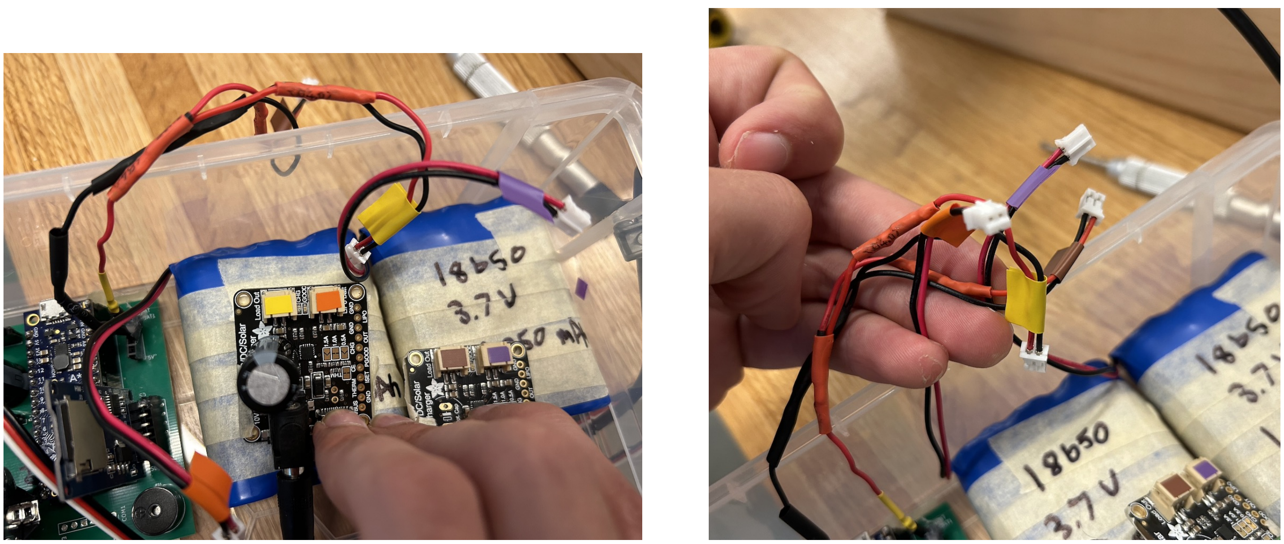


Figure 47: Connections to be plugged in.



(a) Color coded wire ports.

(b) Color coded wire heads.

Figure 48: Color coded plug-ins.

5. Once the microcontroller is plugged in, it will go through the starting sequence. It will wait 5 seconds before setting the servo position to 0, 180, 90, and 0 degrees with a 2-second delay between each move. This should open the radiellos, close them, open them partway, and then fully open them again. After this initialization, the device will check the wind direction every 8 seconds and open/close the device accordingly.

6. To retrieve data from the device, take the microSD card out of the component shown in Figure 32b. The microSD card module is next to where the power cables plug into the PCB. The data is stored as a comma-separated value (CSV) file called DATALOG.txt. After saving the data to your computer or other electronic device, you can delete the DATALOG.txt file from the microSD card and insert it back into the module.

Bibliography

[1] *Adafruit Universal USB / DC / Solar Lithium Ion/Polymer charger - bq24074*. URL: https://www.adafruit.com/product/4755.

[2] *A-Star 32U4 Mini LV*. URL: https://www.pololu.com/product/3103/pictures.

[3] *TianKongRC TS90A 9g Servo Micro SG90 Servo*. URL: https://www.aliexpress.us/item/2251832786499067.html?src=google&gatewayAdapt=glo2usa.

[4] Mehran Maleki. "Interfacing SS49E Linear Hall Effect Sensor Module with Arduino". In: (). URL: https://electropeak.com/learn/interfacing-ss49e-linear-hall-effect-sensor-module-with-arduino/.

A Parts List

Table 5: Parts List

Part	Quantity	Unit Price ($)	Description
Turbine Layer	3	$1.25	3D printed Ugrinsky turbine layers
Turbine Bottom	1	$0.05	3D printed bottom of turbine
Motor Coupler	1	$0.35	3D printed motor coupler
Motor Holder	1	$0.85	3D printed motor holder
Motor Housing	1	$2.00	3D printed motor housing
Motor/Generator	1	$29.30	MXN12FB12F Motor
Solar Manager	2	$14.95	Adafruit solar manager component
Solar Panel	1	$45.00	Adafruit 6V 5W Solar Panel
Battery	2	$29.95	18650 Li-ion Battery Pack
Wind Vane	1	$0.50	3D printed wind vane
Heat Set Inserts	6		Used to connect 3D printed parts together
Wood screws	2		Used for connecting electronics box
Washer	2		Used for connecting electronics box
M2 Fasteners	4		Set screws for motor coupler
M3 Fasteners	5		Set screw for motor and attach holder to housing
8-32 Nut	4		Tightening housing to holder
Electronics Box	1	$5.50	Extra Large Capacity Plastic Pencil Box
Sewing Needle	1		Bottom component of wind vane
Polulu Board	1	$24.95	Pololu A-Star 32U4 Mini LV
Real-Time Clock	1	$4.95	DS3231 AT24C32 Real-Time Clock Module
SD Card Reader	1	$1.46	HW-125 SD Card Reader
Hall Effect Sensor	1	$1.57	9e 24280 Hall Effect Sensor
Servo Motor	1	$7.00	Tiankongrc 9g Micro Servo
Step-Up Transformer	1	$1.00	Regulator Voltage Boost Converter Board 0.9-5V to 5V
	Total Cost	$269.54	