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Radiello-Covering Device

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Radiello-Covering Device

The purpose of this project was to design a field-ready radiello-covering device (RCD) that could cover and uncover a radiello passive sampler. The covering and uncovering periods are determined by the direction that the wind is blowing at any given time. This device was intended to help Dr. Turner and Yan He from WashU's Department of Energy, Environmental and Chemical Engineering to monitor ammonia and hydrogen sulfide air pollutants around concentrated animal feeding operations (CAFOs). This was a continuation of efforts begun in MEMS 312 Multidisciplinary Prototyping & Design in Fall 2023. The design of a radiello-covering device that meets Dr. Turner and Yan He's needs was completed and is ready for further testing in the field.

LIN, Jaimie

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1 Introduction

Many communities located near concentrated animal feeding operations (CAFOs) are concerned with the potential release of pollutants and their impact on air quality and health. To measure the impacts, Dr. Turner and Yan He from WashU's Department of Energy, Environmental and Chemical Engineering are monitoring ammonia and hydrogen sulfide air pollutants around CAFOs. Yan has been using radiello passive air samplers, since they are cheaper than other options on the market. The current setup uses a plastic shelter developed by radiello. The shelters are attached to planks of wood which are bolted to metal poles out in the field, as seen in Fig. 1. A test is run by putting the radiello samplers in the field and leaving them out for 2 weeks. At the end of the test, local residents collect the samplers and mail them back to Yan.

Figure 1: Current Setup.

The issue with using passive samplers is that the source of the pollutants is not able to be determined. Because of this, Yan has tasked us with designing a radiello-covering device (RCD) that covers and uncovers the radiellos based on the direction of the wind. The RCD should operate similarly to the current setup, but with the added ability to automatically cover and uncover the samplers. When the wind is blowing from the direction of the target CAFO, the RCD should uncover the radiellos so that they are sampling pollutants. When the wind is blowing from any other direction, the RCD should cover the radiellos so that they do not sample pollutants from other sources. This helps to ensure that the pollutants measured by the radiellos are coming from (or at least in the direction of) the target CAFO.

This project was a collaboration between Jaimie Lin, Nick Sprague, and Patrick Kirby. Jaimie Lin worked on completing the physical covering and uncovering component. Nick Sprague and Patrick Kirby worked on adding wind and solar components to increase the operation period of the device. This report specifically focuses on the development of the physical covering and uncovering component.

2 Problem Understanding

2.1 Existing Devices

In order to gain insight and background before concept generation, several existing devices with similar functions or useful mechanisms were reviewed.

2.1.1 Existing Device #1: Hydramatic Pool Cover

Figure 2: Hydramatic Pool Cover.

Source: Aquamatic
Link: https://www.aquamatic.com/automatic-pool-covers/hydramatic/
Description: The Hydramatic Pool Cover is a hydraulic automatic pool cover. To open and close the cover, hydraulic motors roll and unroll a tarp over the top of a pool. The all-fluid drive eliminates the need to place electric components near the pool, removing the risk of having to replace expensive electric motors due to flooding. The hydraulic pool cover is safer and more resilient in wet and hostile environments than traditional pool covers which are driven by electric motors.

2.1.2 Existing Device #2: Motion Sensor Trash Can

Figure 3: Motion Sensor Trash Can.

Source: Home Depot
Link: https://www.homedepot.com/p/NINESTARS-13-2-Gal-Hands-Free-Infrared-Motion-Sensor-Trash-Can-Stainless-Steel-Trash-Cab-DZT-50-13/301964409
Description: The Motion Sensor Trash Can features a hands-free lid that opens with the wave of a hand. There is an infrared motion sensor that opens the lid without having to touch it. The trash can also has manual open/close buttons and a power-saving on/off switch.

2.1.3 Existing Device #3: Automatic Fish Feeder

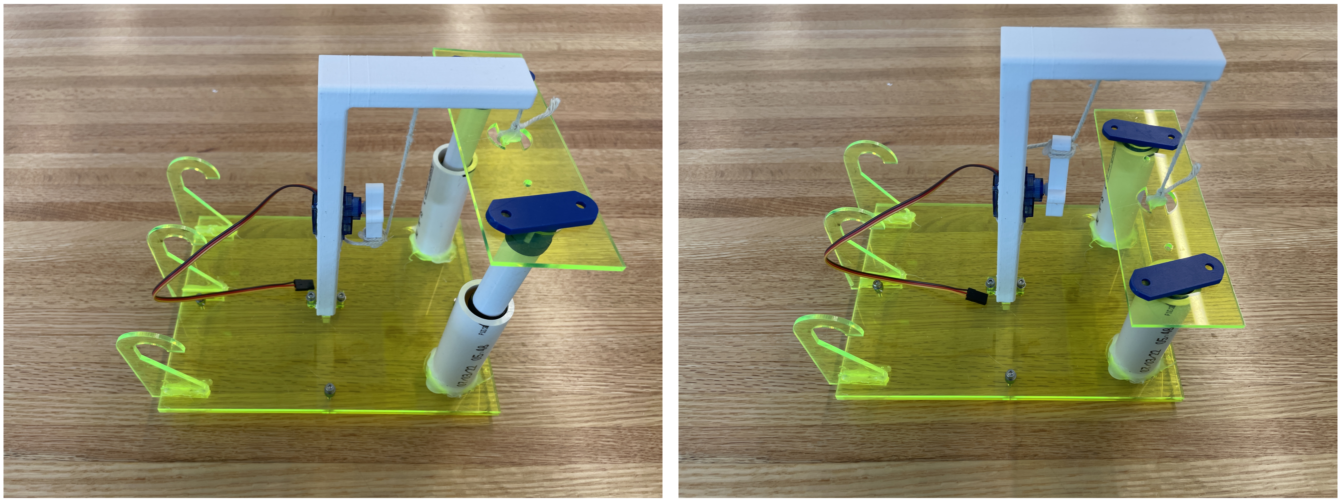
Figure 4: Automatic Fish Feeder.

Source: Petbank
Link: https://www.amazon.com/Petbank-Automatic-Fish-Feeder-Aquarium/dp/B0BB238TCC/ref=zg_bs_g_2975462011_d_sccl_1/144-4693184-5130116?psc=1
Description: The Automatic Fish Feeder is an automated device that feeds aquarium fish based on the selected mode. The feeder rotates to release a small portion of fish food into the top of an aquarium. When one of 3 interval modes is selected, the feeder automatically rotates every 12 hours, 24 hours, or 48 hours. When the manual button is pressed, the feeder immediately rotates for instant feeding. The amount of food released per feeding can be adjusted with a slider that makes the opening larger or smaller. The feeder is powered by a large-capacity battery that last for 3-6 months on a single charge. The feeder can be attached to the top of an aquarium using an adjustable clamp or adhesive sticker.

2.2 Previous Work

Previous prototypes addressing the need for a radiello-covering device were created in MEMS 312 Multidisciplinary Prototyping & Design in Fall 2023. Each previous prototype was reviewed and their strengths and weaknesses were determined.

2.2.1 Previous Prototype #1: Drop Plug

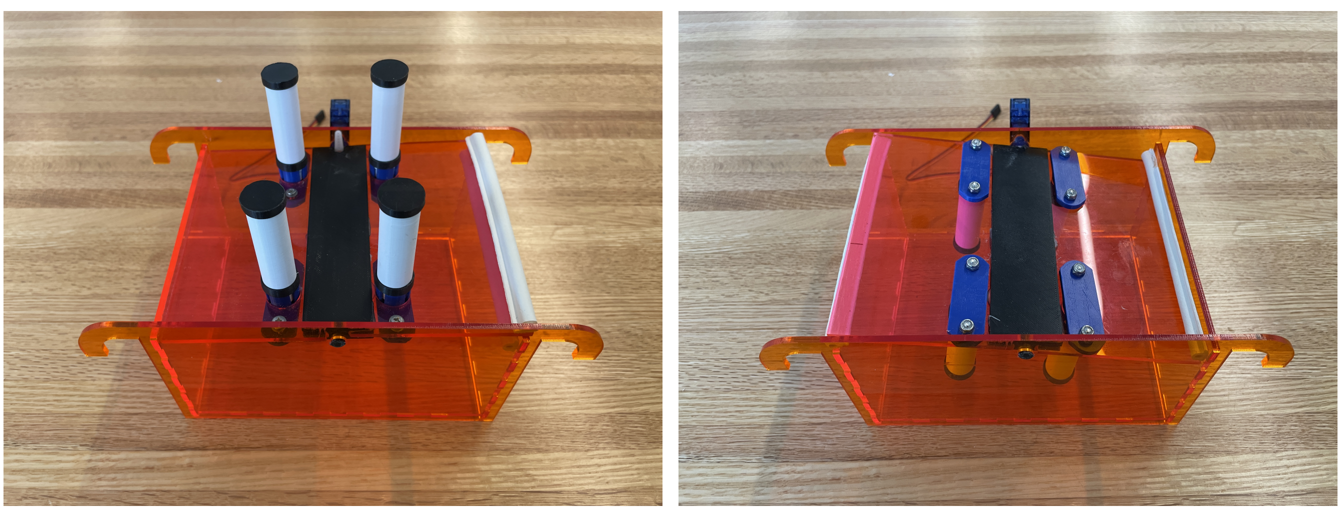


(a) Uncovered position. (b) Covered position.

Figure 5: Drop Plug prototype.

<u>Description</u>: The Drop Plug moves radiellos, which are all attached to a single beam, into and out of tubes using a string. The radiellos are uncovered when they are raised out of the tubes. The radiellos are covered when they are lowered into the tubes. The main advantages are that the amount of air the radiellos are exposed to when covered is minimized and the air flow around the radiellos is only slightly obstructed when in the uncovered position. The main disadvantage is that it is not very robust to strong winds because the beam is hanging from a string, so it could be blown around.

2.2.2 Previous Prototype #2: Flip Top Box

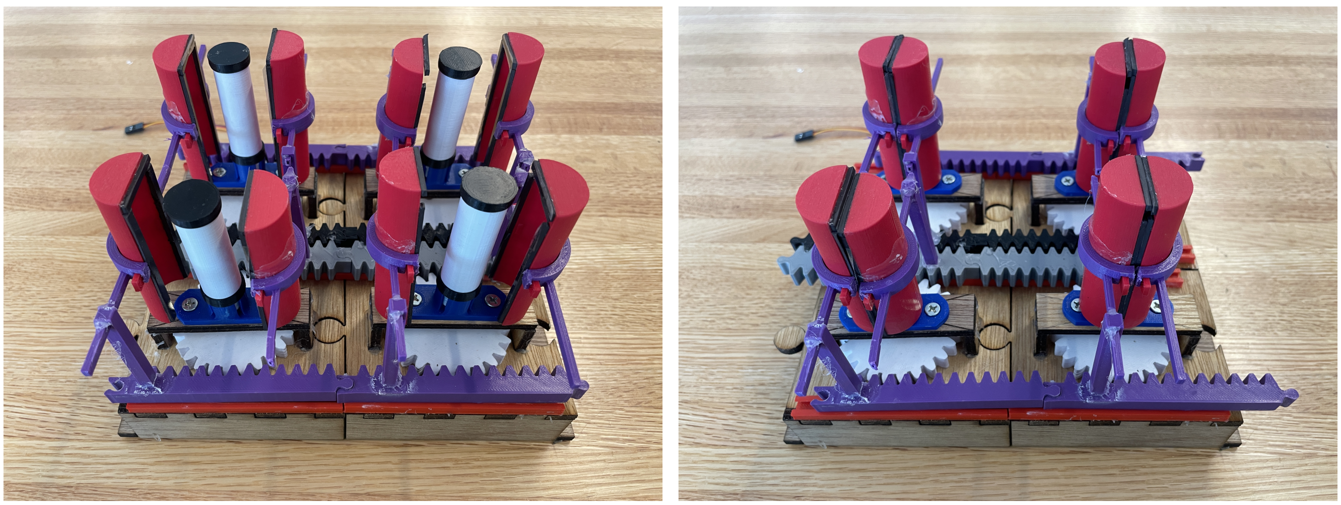


(a) Uncovered position. (b) Covered position.

Figure 6: Flip Top Box prototype.

Description: The Flip Top Box flips a panel 180 degrees to cover and uncover radiellos which are all attached to one side of the panel. The radiellos are uncovered when the panel flips to where the radiellos are on the top, exposing them to fresh air. The radiellos are covered when the panel flips to where the radiellos are on the bottom, encasing them in the box. The main advantages of this prototype are that it can easily be expanded to contain multiple radiellos, the air flow around the radiellos is unobstructed when in the uncovered position, and the risk of debris falling into the box is minimized since the top of the box is closed in both covered and uncovered positions. The main disadvantages of this prototype are that it is relatively large and the servo motor is not strong enough to push the flipping panel into the rubber seal, leaving gaps that air can enter through.

2.2.3 Previous Prototype #3: Sliding Magnetic Case



(a) Uncovered position. (b) Covered position.

Figure 7: Sliding Magnetic Case prototype.

Description: The Sliding Magnetic Case moves two halves of a magnetic case around each radiello using racks and a pinion. The radiellos are uncovered when the two halves of each case are separated. The radiellos are covered when the two halves of each case slide close and are held shut by magnetic strips. The main advantages are that the magnets ensure the radiellos stay covered even in heavy winds and the amount of air the radiellos are exposed to when covered is minimized. The main disadvantages are the overall complexity, the difficultly of including multiple radiellos, and that it takes a great deal of force to separate the two halves of each case.

3 Redesign Process

3.1 User Feedback

At the conclusion of Fall 2023, all of the prototypes generated by the students in MEMS 312 were presented to Dr. Jay Turner and Yan He through a showcase event. At the beginning of Spring 2024, we sat down to discuss the previous prototypes and get their feedback.

3.1.1 Customer Interview

Interviewees: Dr. Jay Turner and Yan He
Attendees: Dr. Jackson Potter, Patrick Kirby, and Jaimie Lin
Location: Jubel 330, Washington University in St. Louis, Danforth Campus
Date: February 1^{st}, 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:
Can you describe the different sampling sites and requirements?

- There are 2 CAFO sites with 2 sampling sites around each.
- They are considering adding 2 more CAFOs for sampling, but it is taking a long time to find residents who are willing to participate near the new CAFOs.

Why were passive samplers chosen?

- They are cheaper than the other options on the market.

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

- Dr. Turner and Yan enjoyed the variety of different mechanisms.
- 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.
- Dr. Potter suggested that linear movement might be the most simple, as the servo wouldn't have to be engaged all the time.

Do you sample throughout the year or only during certain months? (This relates to ambient temperature for the electronics.)

- 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. The samples would then be shipped back to Yan for analysis.

Is an airtight seal important, or are small gaps okay?

- Dr. Turner said that the covers do not necessarily need to be airtight, but there should be a relatively low air exchange rate. The cover should be sealed well enough so that air currents don't enter the device.
- This could be tested by comparing data with the cover (field blank) and without cover (control). For a field blank, it is acceptable if it measures 5-10% of what is measured by the control, but 50% is too much.
- Dr. Turner also mentioned that rain is not a big problem, but the cover shouldn't't collect water.

How accurately do you want to detect wind direction?

- This needs to be tested. Ideally it would be as accurate as possible, however this is not very realistic.
- Dr. Turner said that 30 degrees is ideal, 60 degrees is okay, and 90 degrees is too big.
- Dr. Turner also mentioned that at light wind speeds, the wind direction can be be very irregular.

What information do you want to record, and how often (seconds, minutes, etc.)?

- Dr. Turner proposed that the real question is: How frequently do you need to be measuring to make a judgment about persistence? At light wind speeds, the wind direction can be be very irregular. Because of this, it might be helpful to incorporate a lag time that takes wind persistence into account. For example, we could program the device to only uncover when the wind direction stays constant for 5 minutes.
- We also discussed automatically covering at low wind speeds. An initial cut off of $\frac{1}{2}$ - 1 m/s was suggested.
- Yan agreed to share some wind data that was taken from the sampling sites in order to determine approximately how often the wind changes directions and what the cutoff should be for low wind speeds.

Is there free space on the planks of wood that are already mounted at the field site?

- Dr. Potter presented his idea to mount the device by hanging it over the edge of the plank, much like a shower caddy.
- Dr. Turner and Yan confirmed that there is free space on the planks since they left them slightly longer to eventually add particle monitors. All of the sampling sites have a gray plastic housing already installed, and there is extra plank at the end.

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

- Dr. Turner and Yan have no preference.

Would you prefer if the collected wind and time data were uploaded to the cloud or would it be acceptable to request local residents to replace and mail an SD card along with the radiellos?

- Yes, we can use an SD card.

Would you prefer if the collected wind and time data were uploaded to the cloud or would it be acceptable to request local residents to replace and mail an SD card along with the radiellos?

- Yes, we can use an SD card.

How many number of units should we shoot for?

- Ideally, 4-8 units, but even just 2 would work. Each site needs a minimum of 2 devices, 1 placed upwind, and 1 placed downwind.

Do we need a channel to block wind from other directions?

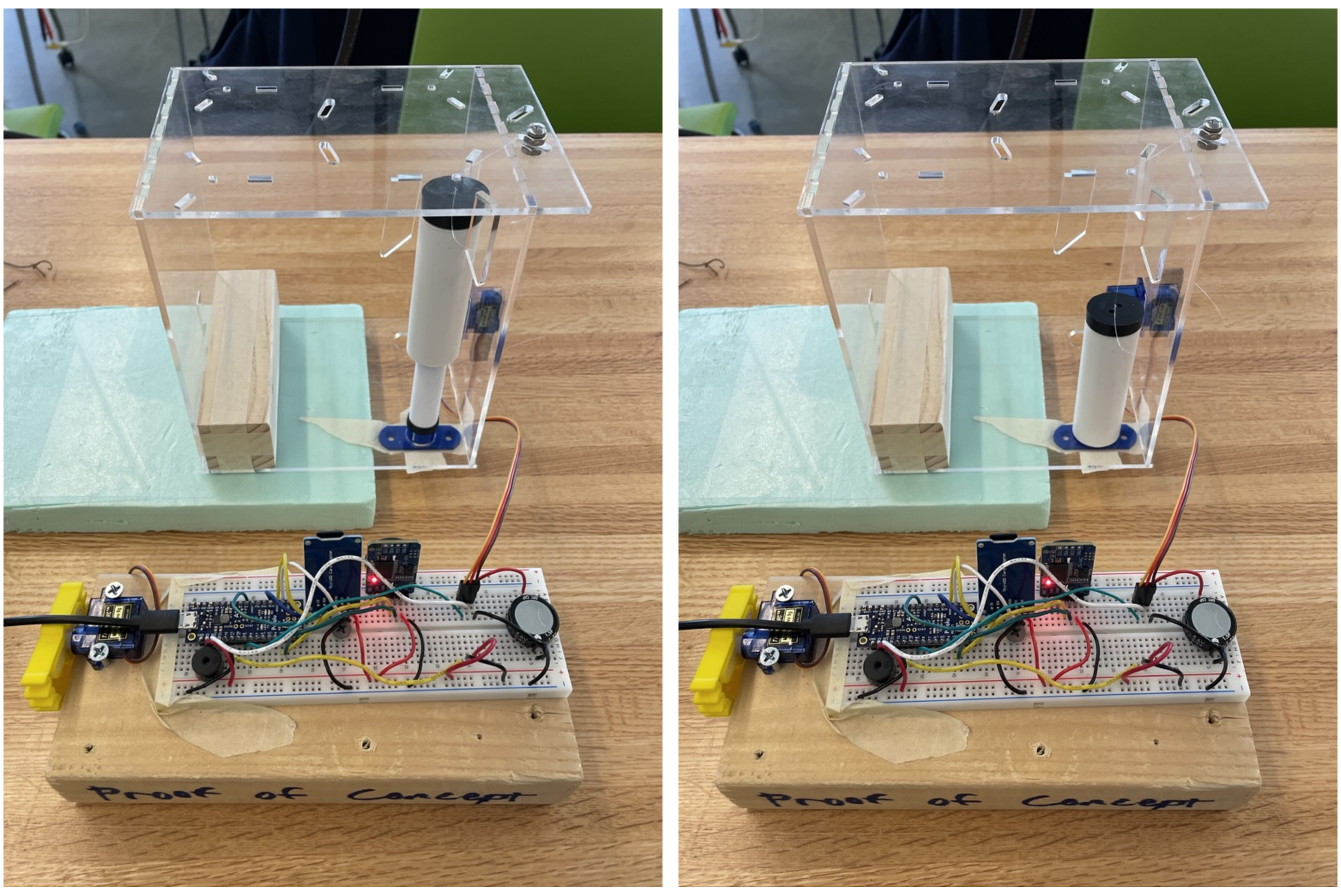
- It does not matter since the air is well mixed at the distance that the samplers are placed. However, the wind vane should be placed in open air to ensure an accurate reading.

3.2 Design Changes

Based on the feedback from Dr. Turner and Yan, a new prototype most similar to the Drop Plug was developed, as seen in Fig. 8. This intermediate prototype included many improvements from previous prototypes. We felt that this new concept retained the main advantage of the Drop Plug which was that the amount of air the radiellos were exposed to when covered was minimized. The new prototype mitigated the main disadvantage of the Drop Plug which was that it was not robust to strong winds. This was done by adding guides to keep the covers aligned when the radiellos were uncovered.

Another improvement included making the PVC cover and tube out of separate parts in order to cut down on the required 3-D printing time. In some prototypes created for MEMS 312 in Fall 2023, these two parts were combined by 3-D printing an integrated tube with a cover. However, these tubes took a lot of time and material to print. Since we had access to a chop saw, it was much faster to cut a PVC tube to length and insert a printed cover. That way, only a small cover needed to be 3-D printed, instead of the entire tube and cover.

A consideration was that the overall structure created by the plates could potentially be replaced by modifying a store-bought box to reduce the number of parts from 4 to 1. However, sticking with laser cutting allowed the precise placement of various holes and features that would be hard to replicate through modifications on a store-bought box.



(a) Uncovered position. (b) Covered position.

Figure 8: Intermediate Prototype.

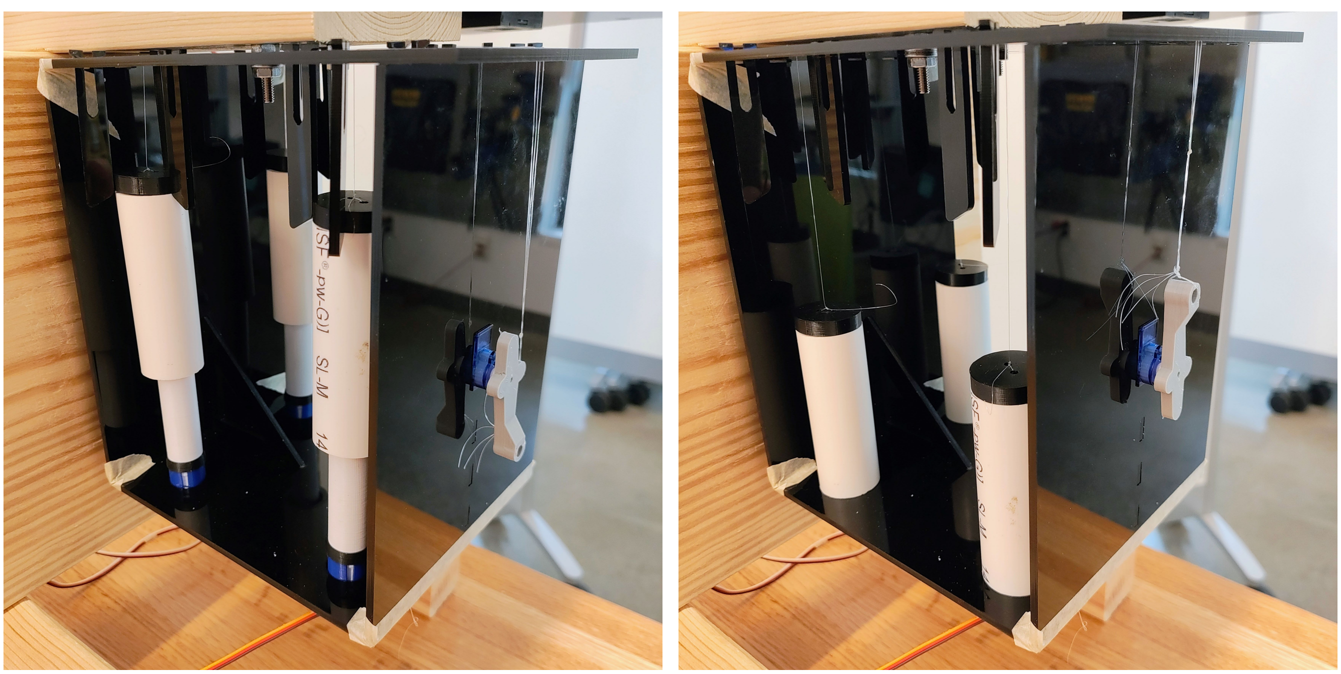
This intermediate prototype worked relatively well, however, there were a few features on the intermediate prototype that were improved for the final prototype. The first problem identified was that the overall structure of the prototype had issues remaining square, i.e., the walls could easily wobble back and forth. This was because the intermediate prototype relied on the snug fit of the tabs in the slots of each plate to keep the overall structure square. This required tight tolerances to ensure a secure fit, which would be difficult to achieve consistently, especially since the acrylic sheets used were not manufactured to a tight tolerance. It would also not be as easily reproducible if the device were to be remade on a different laser cutter or even with slightly different settings. The final prototype included 2 square brackets to improve the stability of the overall structure.

The second problem was that the cover guides were not very secure. In the intermediate prototype, the guides were solid tabs that slotted into holes on the top plate. Similar to the issue with the overall structure remaining square, making the tabs secure requires tight tolerances that are difficult to achieve consistently. To mitigate this issue, the guides were redesigned to incorporate compliant tabs which locked the guides in place once inserted and allowed for a wider range of tolerances.

Another problem with the intermediate prototype was how difficult it was to remove the radiellos from the device. There was not enough space to move the radiello covers out of the way so that the radiellos could be pulled out of the holders. This was fixed in the final prototype by increasing the overall height of the device so that there would be more room to move the covers, making the radiellos more accessible.

3.3 Final Prototype

The final cover prototype, as seen in Figure 10, was successful overall. The greatest improvement from the previous prototypes created in Fall 2023 was that the device was made robust to the wind. This was done while continuing to expose the radiellos to a minimal amount of air while covered and keeping complexity to a minimum.



(a) Uncovered position.

(b) Covered position.

Figure 9: Final Cover Prototype.

3.4 Final Integrated Device

After the completion of the covering component, it was then integrated with the wind and solar components, as seen in Figure 10. The final integrated prototype operated successfully for several days during initial testing. Further testing is needed to determine the longevity of the device and whether or not it will hold up to the elements.

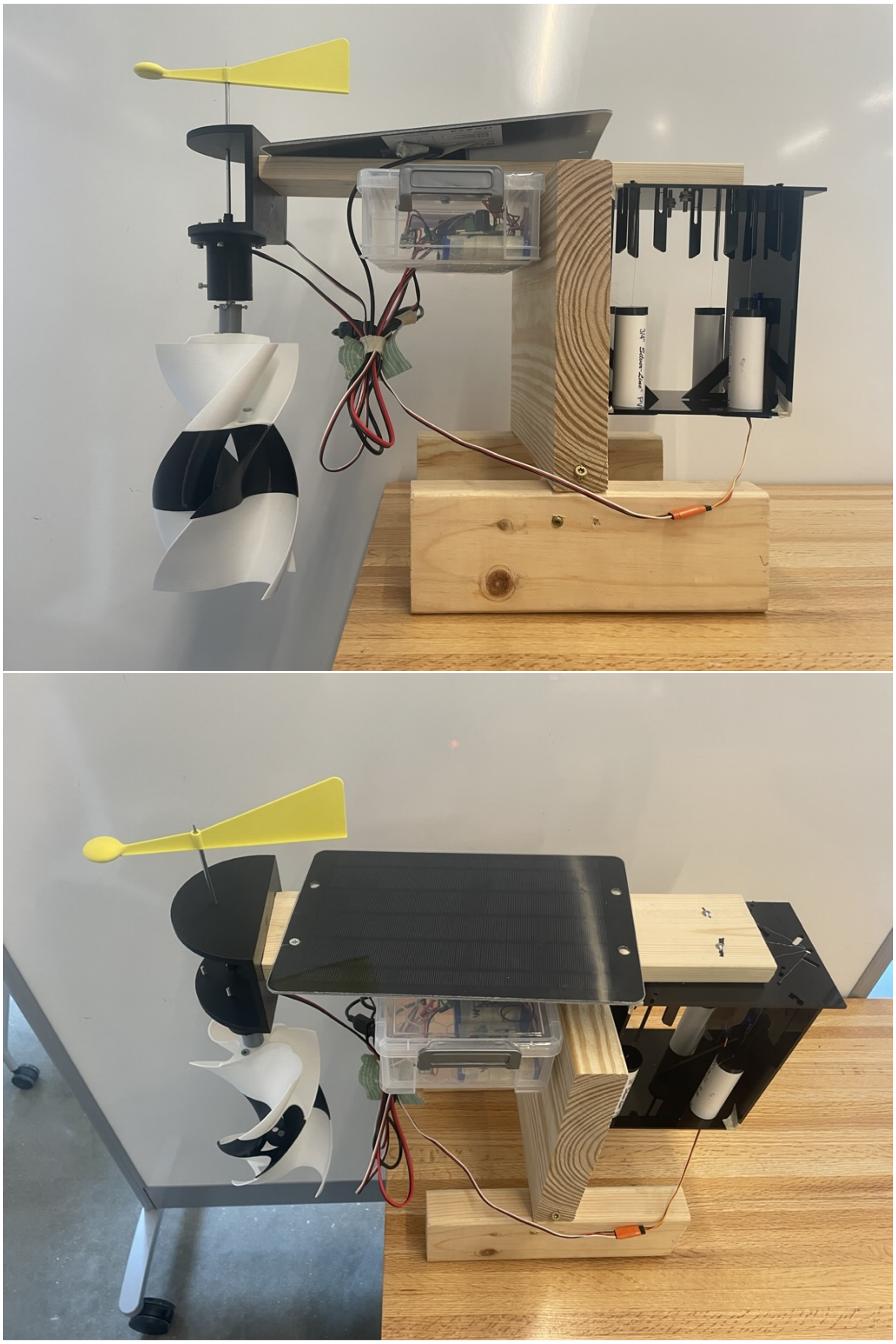


Figure 10: Final RCD.

A Description of Parts

A.1 Overview

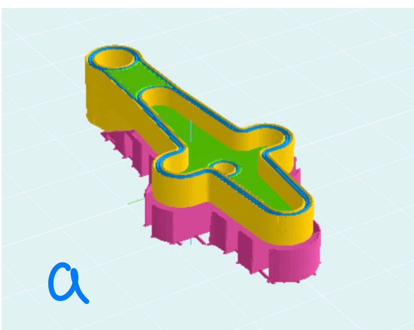
The final cover prototype contains a total of 36 parts: 9 3D printed parts, 18 laser cut parts, 8 modified store-bought parts, and 1 unmodified store-bought part, as summarized in Tab. 1. The servo arm, PVC covers, and radiello holders were 3-D printed out of PLA. The plates and guides were laser cut out of acrylic sheets. The PVC tubes and string were cut from stock material using a chop saw and scissors, respectively. The servo motor is a unmodified store-bought part. The total cost per device comes out to just over $7.

Table 1: Parts List.

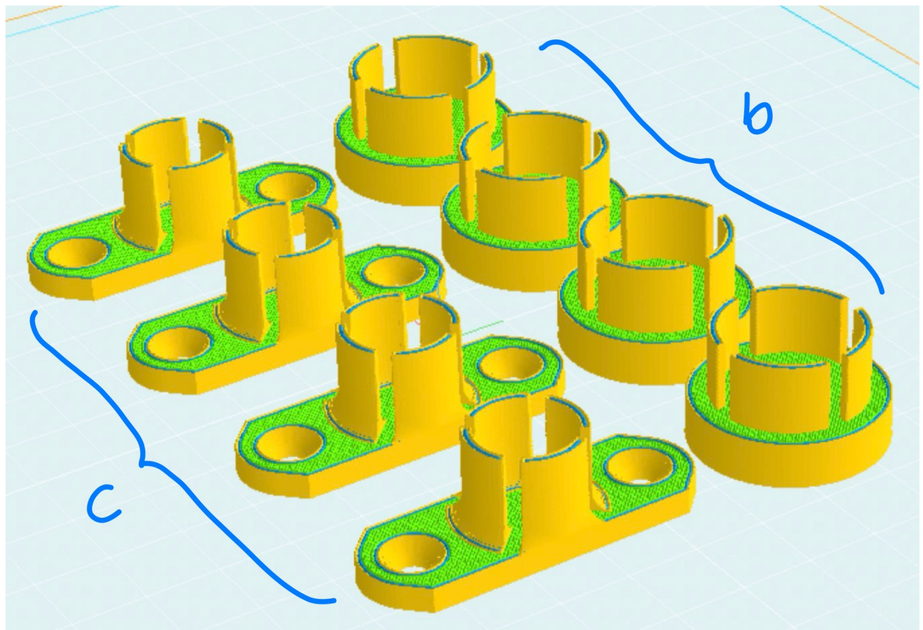
	Part	Source	Material	Part Specs	Unit Price	Qty.	Total Price
a	Servo Arm	3D Printed	PLA	Weight: 2.39 g Time: 21 min	$0.31	1	$0.31
b	PVC Cover	3D Printed	PLA	Weight: 3.06 g Time: 32 min	$0.11	4	$0.44
c	Radiello Holder	3D Printed	PLA	Weight: 2.75 g Time: 22 min	$0.10	4	$0.40
d	Top Plate	Laser Cut	1/8" Acrylic	Surface Area: 33.6 in^2	$1.40	1	$1.40
e	Side Plate	Laser Cut	1/8" Acrylic	Surface Area: 36.2 in^2	$1.51	1	$1.51
f	Servo Side Plate	Laser Cut	1/8" Acrylic	Surface Area: 36.2 in^2	$1.51	1	$1.51
g	Bottom Plate	Laser Cut	1/8" Acrylic	Surface Area: 30.0 in^2	$1.25	1	$1.25
h	Bracket Plate	Laser Cut	1/8" Acrylic	Surface Area: 3.7 in^2	$0.15	2	$0.31
i	Cover Guide	Laser Cut	1/8" Acrylic	Surface Area: 1.1 in^2	$0.05	12	$0.55
j	PVC Tube	Home Depot	PVC	Inside Diameter: 3/4" Length: 3"	$0.14	4	$0.56
k	String	Amazon	Nylon	Clear Fishing Wire	$0.01	4	$0.04
l	Servo Motor	Tiankongrc	Plastic	Micro Servo 9g with Analog Plastic Gear	$2.59	1	$2.59
Total							$7.09

A.2 3D Printing

The 3D printed parts for this project were printed in PLA on an Original Prusa i3 MK3(S/S+). The print settings used were: 0.15 mm layer height, 0.8 mm wall thickness, 15% infill density, and no rafts. The Servo Arm was printed with generated supports while the PVC Covers and Radiello Holders were printed with no support. The recommended 3D-printing orientation of all the parts is shown in Fig. 11. The print time for the Servo Arm is 21 minutes. The Servo Arm filament weight is 2.39 g and the cost is $0.31. The print time for the PVC Covers and Radiello Holders is 3 hours and 46 minutes. The Servo Arm filament weight is 23.63 g and the cost is $0.84.



(a) Servo Arm.



(b) PVC Covers and Radiello Holders.

Figure 11: 3D Printed Parts.

A.3 Laser Cutting

The laser cut parts for this project were cut from 1/8" extruded acrylic sheets using an Universal Laser Systems v6.60. All of the parts can be cut from a 18" x 12" sheet of acrylic using the layout shown in Fig. 12.

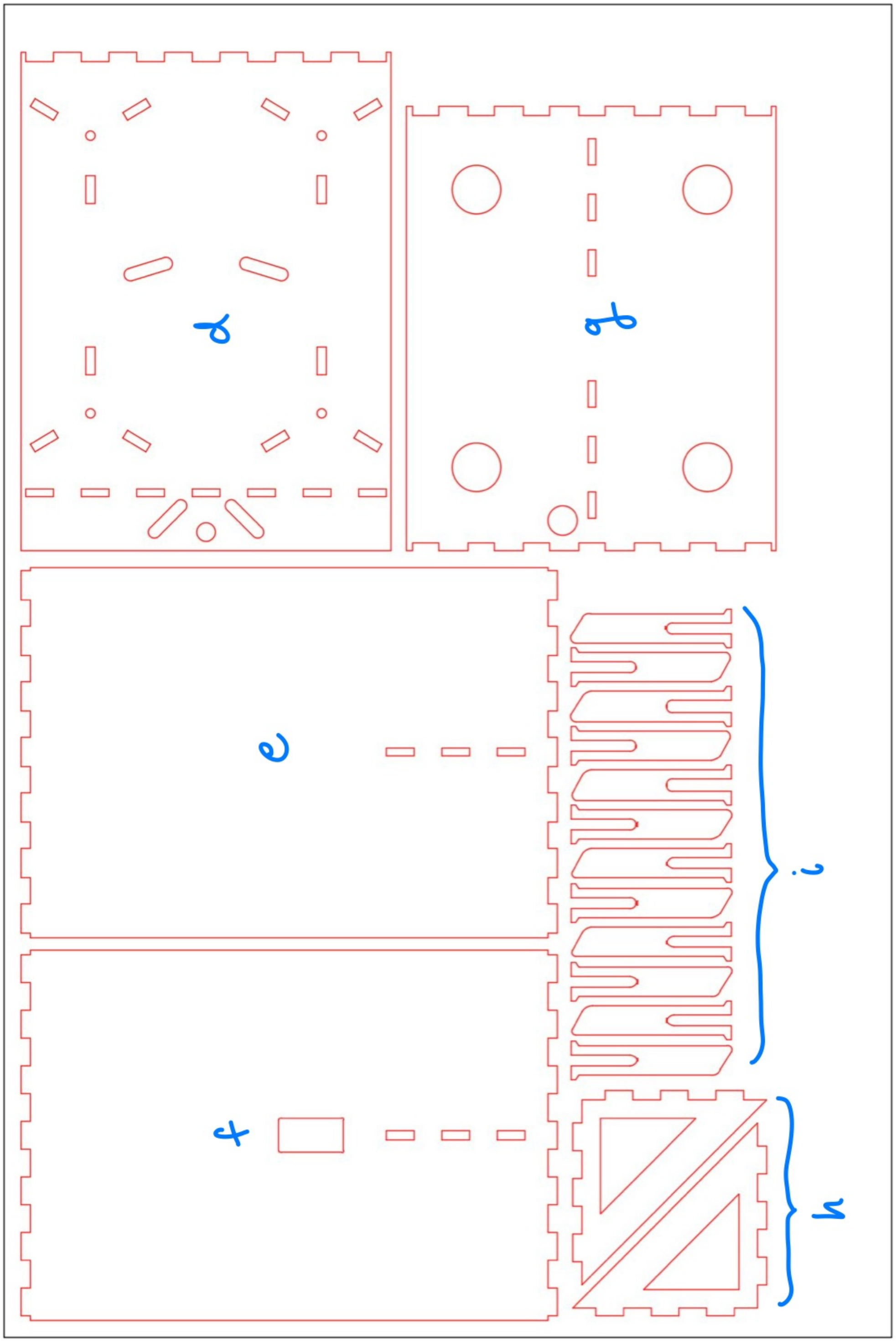


Figure 12: Laser Cut Parts.

B Instructions for Installation

Step 1. Place the RCD over the wooden plank and secure using 2 wood screws as shown.

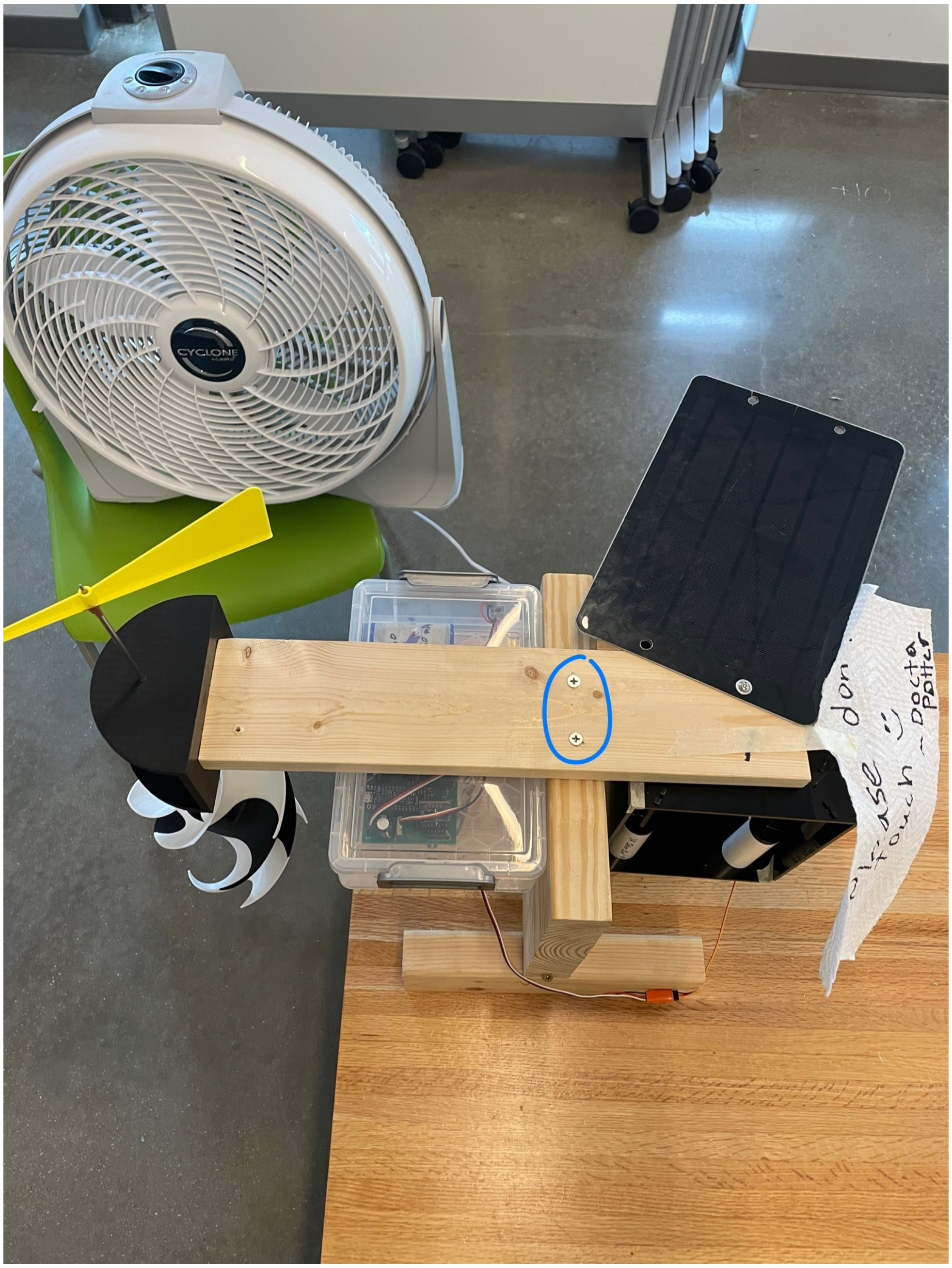
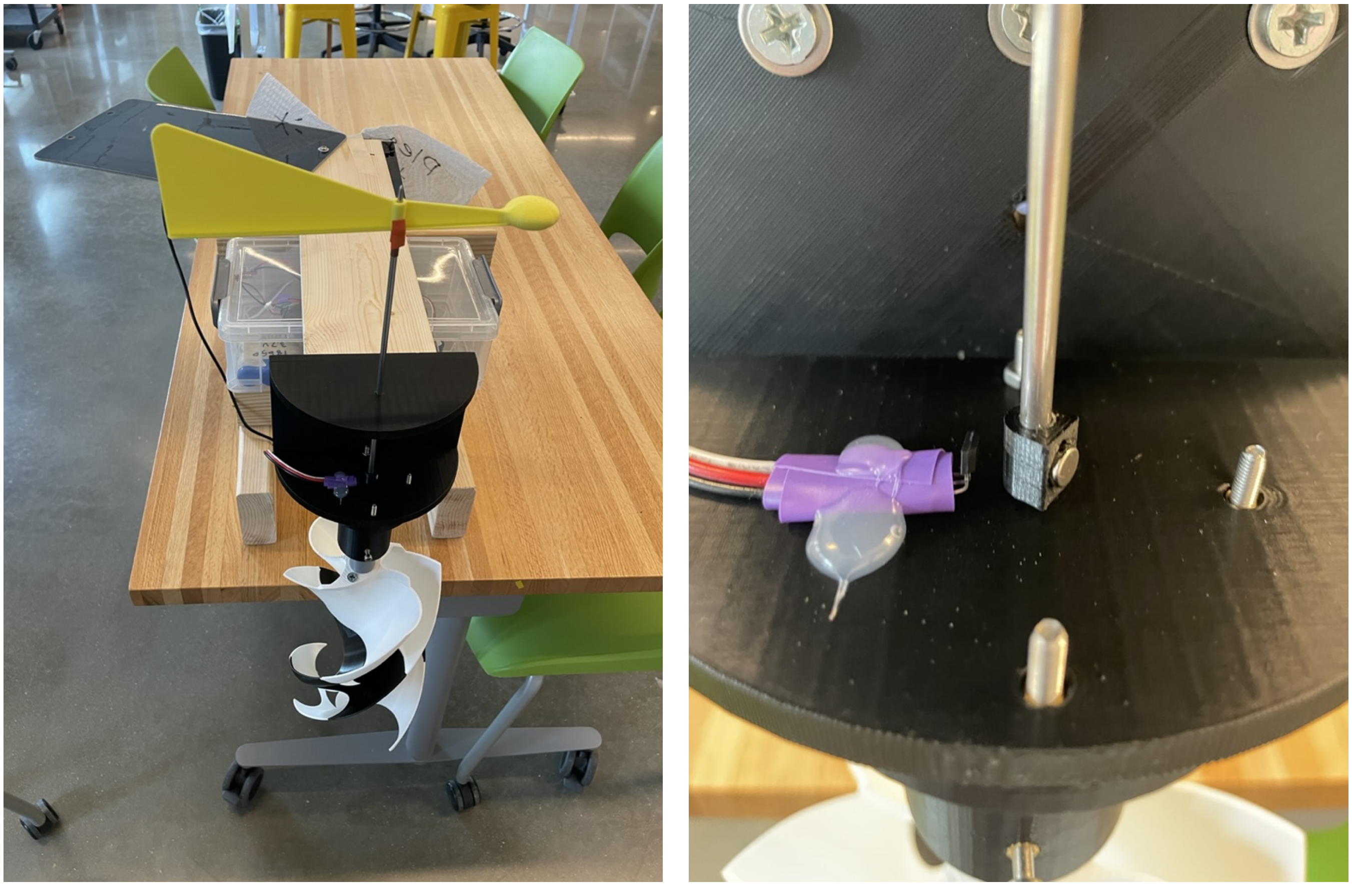


Figure 13: Installation Step 1.

Step 2. Orient the wind vane in the direction of the target CAFO. This determines when the radiellos are uncovered.

Step 3. While holding the wind vane still, rotate the magnet until it faces the Hall effect sensor.



(a) Installation Step 2.

(b) Installation Step 3

Figure 14: Installation Steps 2 and 3.

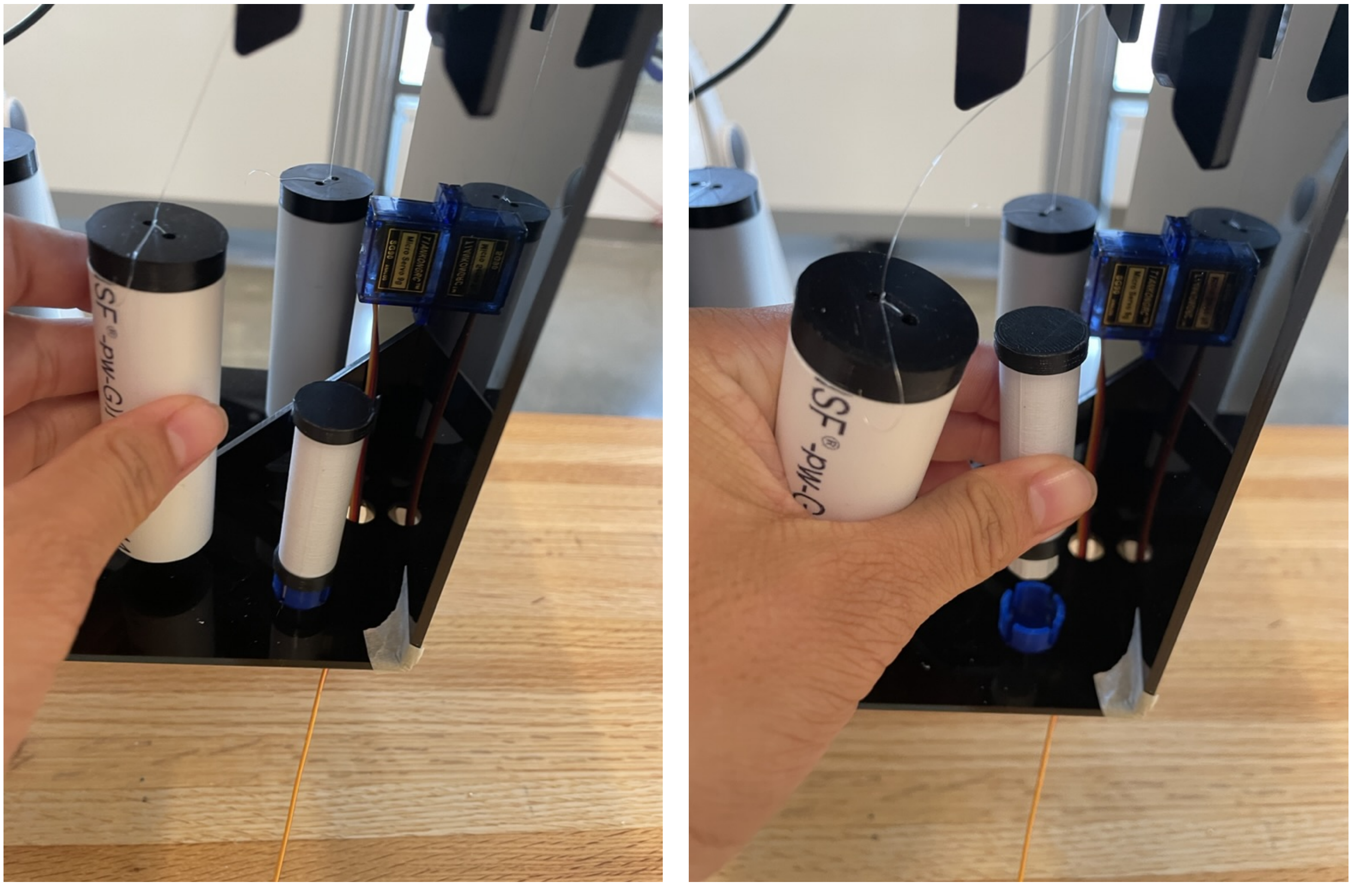
C Instructions for Collecting Samples

Step 1. Lift up the cover to reveal the radiello sampler.

Step 2. Remove the radiello sampler.

Step 3. Replace the cover over the newly inserted radiello sampler.

Step 4. Repeat Steps 1-3 for all other radiello samplers.



(a) Sample Collection Step 1. (b) Sample Collection Step 2.

Figure 15: Sample Collection Steps 1 and 2.