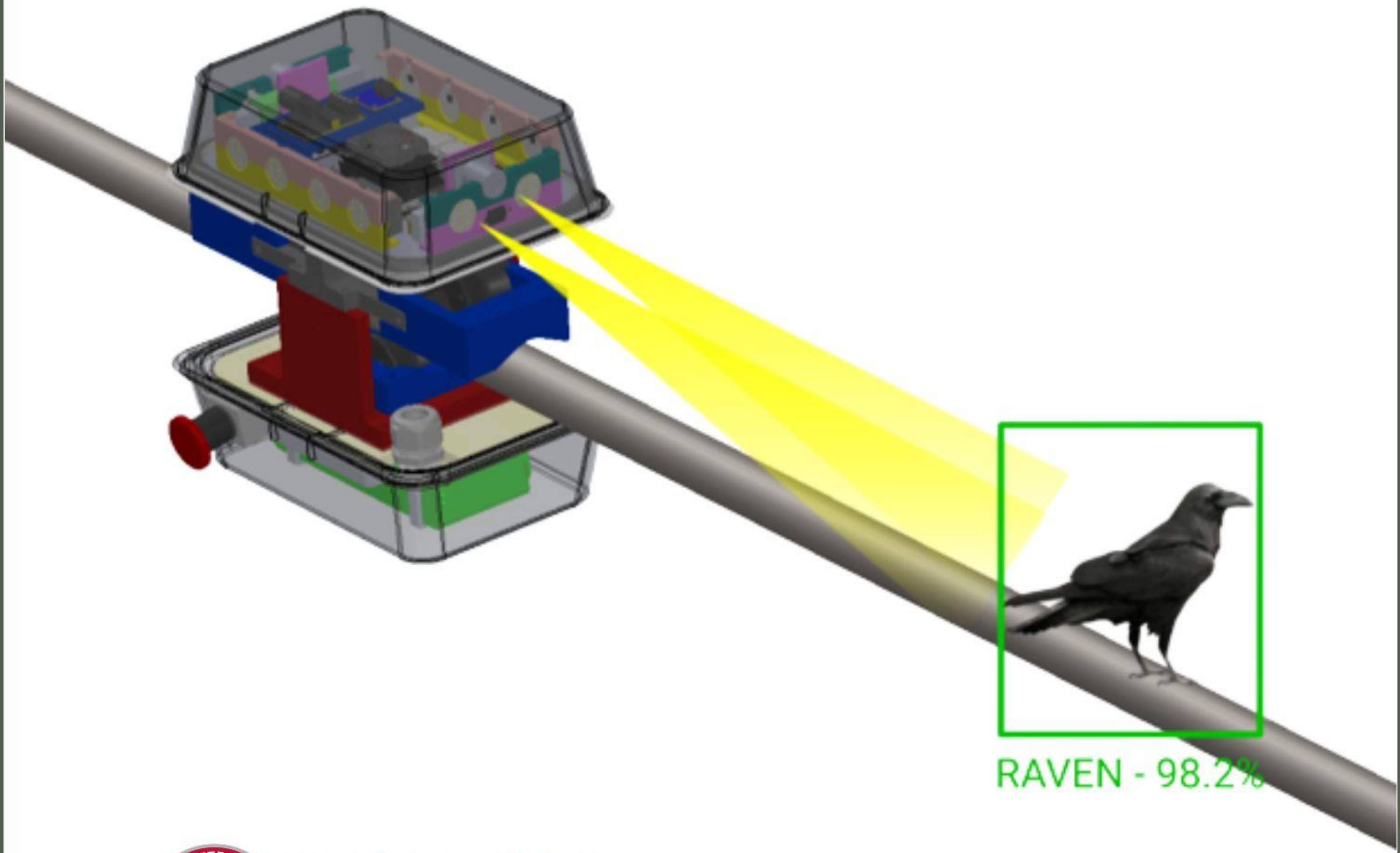
BIRD DETERRENT ROBOT

DETERRING RAVENS FROM COMMERCIAL ENERGY SUBSTATIONS



WPI EVERSOURCE

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Submitted To:

Professor Gregory Lewin, Professor William R. Michalson, and Professor Jing Xiao

Robotic Bird Deterrent

A Major Qualifying Report

Submitted to the Faculty of

Worcester Polytechnic Institute

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Abstract

Occasionally causing power outages for up to 10,000 customers, ravens continue to damage equipment at Eversource Energy's Rimmon Substation in Goffstown, New Hampshire. To address this issue, a project team previously created a bird deterrent prototype that used an ultrasonic rangefinder to detect cormorants and used flashing lights and sound to deter them. In an effort to improve upon the previous prototype, a bird detection model using artificial intelligence (AI) was added to the system. This AI detection model can recognize the presence of a raven, notify the system, and activate a set of deterring stimuli. Additionally, new sensors for bird detection were incorporated, including a laser-based "Time of Flight" (ToF) sensor that detects the bird's proximity. A mobile application was also created for Eversource employees to remotely monitor and control the robot while it is deployed on the wire. To ensure durability, the electrical housings were redesigned to include weatherproofing and ensure mechanical stability, and a new docking charging station that wirelessly charges the robot using solar energy was introduced. These improvements are expected to enhance bird detection accuracy, system robustness, and user experience.

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1.0 Introduction and Background

Electricity is a vital component in everyday life. Eversource is a major electricity provider serving customers in New England since 1966. The company prides themselves on making their electricity systems “smarter and more resilient to disruptions” (Eversource, 2022). Recently, Eversource has encountered unexpected difficulties due to avian activities in and around their power infrastructure. Birds such as cormorants and ravens are known for damaging electrical infrastructure and are a leading concern for Eversource.

1.1 Avian Concerns

Eversource received reports of cormorants roosting and drying their wings on power lines over Cedar Pond in Cape Cod, Massachusetts (*Double-Crested*, n.d.). While perching on powerlines, cormorants defecate into the pond, causing chemical imbalances in the water and threatening local wildlife. Cormorants are aquatic birds, but their feathers are not fully waterproof as they lack the necessary oil glands. The lack of oil results in their feathers getting waterlogged, therefore cormorants are often seen drying their feathers, standing with their wings in the direction of the sun or breeze on power lines (Cornell, 2022). Additionally, cormorants are a loud species, disturbing residents who live nearby said roosting locations.

Ravens have become a significant issue at Eversource’s Rimmon Substation[1] in Goffstown, NH, due to their increasing population and nesting habits. These large birds are members of the *Corvidae* family and have wingspans of over 4.5 feet. They can live up to 13 years in the wild and are known to use urban areas as nesting locations. Ravens actively forage through all times of daylight and roost together at night. In February, raven nests can hold up to 7 eggs, which hatch during March and April. Despite carrion and roadkill being their primary food source, they are opportunistic omnivores, making them capable of exploiting new food sources such as those found at the substation. Studies have shown that ravens are more likely to build nests on power lines than other natural landscape features. Unfortunately, their nesting habits have caused a significant increase in power outages, as they peck at the high-voltage and ground power lines

[1] A location containing electrical equipment that reduces high voltages for consumer use.

and carry debris onto electrical equipment. Eversource has been trying to find ways to deter the ravens for years, as these outage issues are a major concern.

Raven behavior drastically changes based on their setting. They have demonstrated the ability to evaluate specific dangers and adjust behavior through social-based learning. This suggests that once a raven deterrent ceases to successfully deter ravens, it will also be useless as a deterrent for the next generation. A study has shown that in rural settings, ravens are more discouraged by humans than in urban settings (Knight 1984). In urban settings, humans are less likely to harm ravens and harass them, in turn causing ravens to be more likely to harass humans that come near their nest. Deterrents that successfully deter ravens initially may cease to work after prolonged exposure. In addition, any behaviors that may be reinforced by deterrents are passed on to offspring (Marzluff & Angell, 2005). Therefore, an adapting solution was necessary.

1.2 Eversource's Bird Deterring Methods

For many years, Eversource has attempted to deter a variety of birds from their electrical infrastructure. These birds include but are not limited to Cormorants and Ravens. While deterring birds, Eversource has dealt with multiple political, social, and physical challenges.

1.2.1 Cormorant Deterring Methods

Since the mid-1990s, Eversource has met with a variety of government and conservation organizations to determine solutions to problematic cormorant populations at Cedar Pond. In 1995, Eversource developed an elastic rope to use over the pond, but it did not prevent the cormorants from landing on the rope, defecating, and then flying away (Jessa, 2016). In 2015, after more communication with government organizations and conservation groups, the US Department of Agriculture (USDA) created a series of bird deterrents to test dispersal measures of cormorants. The USDA implemented pyrotechnics[2], lasers, and physical harassment to deter the birds (Jessa, 2016). The tests were shown to be successful with a 72% reduction of birds spotted on the wires for the month of August 2015, when the test was conducted (Jessa, 2016). In 2018 at Cedar Pond, further testing with auditory and visual scare tactics was conducted on cormorants. The auditory scare tactics included alarm and distress calls played over loudspeakers, exploding shells, and automatic gas exploders. The visual scare tactics included kites, balloons, reflectors and lasers. The main findings from these tests were that the deterrents succeeded initially but then the birds became desensitized to their presence (Eichner et al., 2013). In order to limit the bird access to Cedar Pond, Eversource has researched relocation of the power lines over the pond. Eversource determined the current power lines could be replaced in the following ways: rerouting the power lines around the pond, burying the lines underground, placing the lines at bottom of the pond, or using smaller diameter lines to replace the existing lines. These line replacement solutions all carry a cost of between $915,000 and $2,600,000 (Jessa, 2016).

[2] the art of making or the manufacture and use of fireworks

1.2.2 Raven Deterring Methods

Figure 1: Inflatable deterrent and dead raven deterrent from Rimmon Substation (GZA GeoEnvironmental Inc., 2018)

At Eversource's Rimmon Substation in Goffstown, New Hampshire, ravens frequently cause power outages by pecking at high-voltage switches. Management at the substation has implemented multiple raven deterrents in their raven management plan: plastic coverings, inflatable deterrents, bird repellent spray, and raven effigies. The effectiveness of these deterrents has been studied by GZA GeoEnvironmental Inc and reported in their common raven assessment report.

Plastic coverings were found to be ineffective; ravens chewed through the plastic insulators placed to deter them. However, the coverings had the opposite effect and led to an increase in raven activity. Ravens are naturally attracted to new objects leading to the destruction of the new plastic.

Inflatable devices, better known as "wacky inflatable tube men," as depicted in Figure 1, were found to be effective when in place with the other deterrents. However, like many of the other deterrents they were only temporarily effective, and the units needed to be moved regularly to remain effective.

Bird repellent spray (methyl anthranilate) is a viable deterrent to reduce raven activity and is currently in use at Rimmon Substation. However, methyl anthranilate is known to cause pain in the bird's upper beak and the effectiveness of this spray has varied widely between studies. Therefore, bird deterrent spray could serve as a component in a multi-deterrent approach but should not be used on their own.

Another deterrent used at the substation was the carcass of an accidentally electrocuted bird placed on the top of the substation control building. In another study it was found that "that effigies (i.e. carcasses and taxidermic specimens) reduce average corvid abundance and incidence within 50 meters of effigies by 27 to 70%," (GZA GeoEnvironmental Inc., 2018). Raven effigies are currently being considered as a long-term management option at the substation.

The newest deterrent added to the substation was a laser-based system. The system is placed on a tall pole above the substation to shine an array of class II laser beams at a bird within the substation fence. While the effectiveness of the system has not officially been tested, Eversource officials anecdotally reported less raven activity since the time of installation.

Cannons and horns are recommended deterrents that have yet to be tested at the substation (GZA GeoEnvironmental Inc., 2018). GZA GeoEnvironmental also stated, cannons can have a "sound pressure of approximately 130 dB at a one-meter distance, and different models can account for wide angle motion, long-range motion, and remote-control firing from up to a mile away." However, cannons would not be an adequate solution for the Bird Deterrent Robot as they have a high potential to disturb surrounding residences. There is also the possibility that the ravens will acclimate to the firing sound. Finally, "hand-held laser rifles have been shown to effectively reduce raven activity to protect desert tortoises." These laser rifles emit a "532 nanometer green light, which functions as a visual irritant to ravens" (GZA GeoEnvironmental Inc., 2018).

1.3 WPI Contributions

A team from WPI began developing a robotic deterrent for cormorants in 2021. Though the robot has not been deployed, ideas from the initial prototypes have served as inspiration for the new iterations that aim to detect and deter cormorants and ravens, respectively.

1.3.1 Previous Year MQP

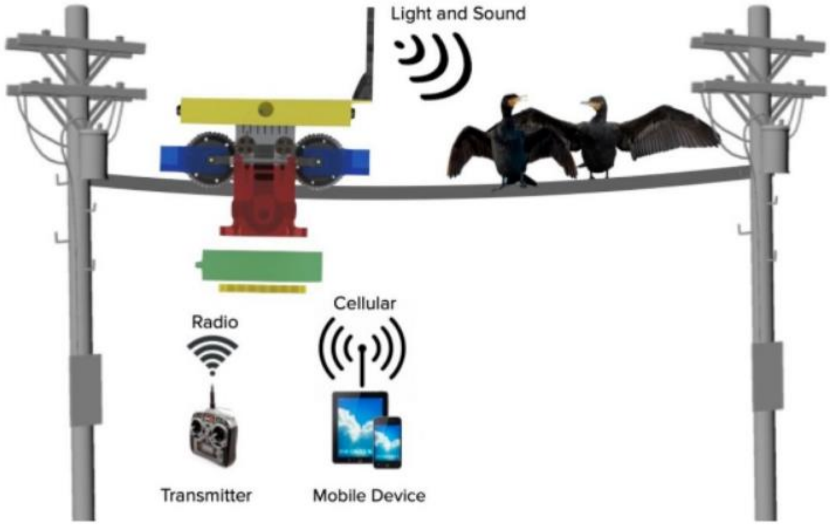

Figure 2: Diagram of the system from 2021-22 MQP

In 2021, the development of the Robotic Bird Deterrent began; the robot aimed to alleviate cormorant-related issues at Cedar Pond in Cape Cod. The robot aimed to "patrol a power line and deter birds from landing or resting on the line...to evaluate the effectiveness of different bird deterrent methods and prove autonomous operation" (Kadoya, 2021). The prototype had a drive train to patrol the wires, and multiple deterrents (light and sound). An artificial intelligence (AI) program was created to detect bird species. A docking system was created to charge the robot at the end of the power line. Users may control the robot via a mobile app or with a radio transmitter and controller. The app, however, also allows users to monitor key functions of the robot while it operates autonomously (Figure 2).

The Robotic Bird Deterrent system is still in a prototype stage. Many electronic connections were made through jumper wires which are not suitable for the final design as they often come loose. In addition, the body of the robot is currently 3D printed for the purposes of rapid prototyping. However, Polylactic Acid (PLA) is not suitable for outdoor conditions because water can degrade the material. Also in the prototype, some electrical components are mounted with Velcro which is useful for continuously removing components while prototyping. However, Velcro is not a secure mounting method and suitable for withstanding vibrations of the final system. Lastly, the electrical components are housed in semi-sealed containers which are useful for dry conditions but will not withstand rain. The faulty electrical connections and water susceptible components will have to be addressed before the robot is ready to be deployed.

1.3.2 Testing Complications

While the Robotic Bird Deterrent system prototyped in 2021 demonstrated functionality in lab conditions, concerns arose regarding viability for testing at Cedar Pond. Issues revolved around reliability in outdoor environments as well as safety for all animals present. The robot must also differentiate between cormorants and endangered birds, as the robot is not allowed to interfere with any endangered avian species. Before the robot can be implemented at Cedar Pond, further iterative designing and testing must be conducted to better calibrate the robot to the testing environment.

Generally, testing on power lines is a complicated process. In such, rerouting power from any given line is a time consuming and laborious task. Therefore, there are few power lines that this team may use to test the robot. Eversource has offered to provide us with a deactivated transmission line at Cedar Pond. However, the addition of the deactivated power line does not solve the issue of mounting and unmounting the robot on a power line located far from the ground, so an alternate testing site was established until a more solidified prototype could be developed.

1.3.3 Rimmon Substation Testing Site

Eversource proposed moving the testing location to Rimmon Substation in Goffstown, New Hampshire. The new location suffers from ravens shorting high voltage connections, causing power outages for about 10,000 customers (GZA GeoEnvironmental Inc., 2018). Testing at the Rimmon Substation will not require rerouting power as Eversource has offered to install an unpowered wire at ladder height for more accessible testing. Testing at this new location raised complications. While cormorants are located only along the wire, the ravens at Rimmon Substation are not restricted to being only on the unpowered wire.

2.0 Problem Statement

To help Eversource, the team proposed to develop a bird deterrent robot to autonomously deter ravens from tampering with high-voltage switches at Rimmon Substation. The proposed Bird Deterrent Robot used Artificial intelligence to detect and classify ravens. The robot uses visual and auditory methods, such as strobing LED lights and loud pulsing sounds from speakers, to deter ravens. To improve robot longevity and reliability, emphasis was placed on creating a weatherproof system that can withstand New England's diverse climate and prolonged use at the substation.

3.0 Project Needs and Requirements

In order to meet the goals and objectives that best suit the project, the following needs were generated. These "needs" were informed by evaluating guidelines set by Eversource, official laws and regulations, as well as our abilities as students.

3.0.1 Detect and classify birds on and off the power line.

The Bird Deterrent Robot should be capable of detecting birds located on or near the unpowered cable. Eversource will be implementing the bird deterrent robot at the Rimmon Substation, where birds have been damaging nearby electrical equipment and shocking themselves in the process, leading to power outages. The robot's bird detection should be able to distinguish differences between bird species and other wildlife.

3.0.2 Deter birds autonomously while on a power line

The Bird Deterrent Robot should be capable of deterring ravens autonomously while on a power line. Ravens need to be deterred away from Eversource's electrical equipment at the substation, to protect both the birds and the electrical equipment. In addition, the robot should be able to operate autonomously with little to no additional support from a human operator.

3.0.3 Avoid harming birds or other wildlife

The Bird Deterrent Robot should not harm any birds or other wildlife. Many species of birds are protected, and legally cannot be harmed or disturbed by humans or machines.

3.0.4 Allow control by user when needed (tele-operation).

The Bird Deterrent Robot should be able to be remotely controlled within the substation. Eversource wants to be able to control the robot using teleoperation while it is patrolling the power line in case the robot needs to be brought back to the base point. Furthermore, complete control of the Bird Deterrent Robot is necessary at times for safety reasons.

3.0.5 Withstand varying weather conditions on an outdoor power line in New England

The Bird Deterrent Robot should withstand varying weather conditions that may occur outdoors in New England. The robot will have many electronic components which will be outdoors at the Rimmon Substation. These electronic components should be protected within the robot in such a way that they will not get damaged due to external weather conditions.

3.0.6 Allow reliable and repeatable mounting and dismounting by a single user on the cable.

The Bird Deterrent Robot should be installable and removable on a power line by a trained Eversource employee. Some of the wires at the Rimmon Substation may only be ladder accessible. An Eversource employee should be able to install and remove the Bird Deterrent Robot on their own if they deem it necessary.

3.1 Requirements

To meet the previously mentioned needs, the following requirements were established. A more detailed version of this list can be found in Appendix I.

The Bird Deterrent Robot shall:

1. Autonomously patrol the power distribution cable for at least 9 hours.
2. Climb a maximum inclination of 30 degrees without slipping.
3. Detect birds within 360 degrees of the robot that are landing on power distribution cables.
4. Cause a bird to voluntarily leave the 20m x 20m area within 15 seconds.
5. Stop before contact with objects on the power cable.
6. Implement IP67[3] rating to withstand varying extreme weather conditions.
7. Perform teleoperation with wireless manual control through radio communication from within the substation.
8. Be mountable by a single technician in under X minutes without the use of tools.
9. Operate for a year without maintenance.

[3]Ingress Protection 67, IP67, is a standard for weatherproofing that states the device can withstand contact with objects greater than 1mm, complete dust resistance, and can be submerged up to 1 meter underwater for a short period of time (Trick, 2021).

4.0 Intermediate Testing: Birdbox

A testing environment named "Birdbox" was created to test the robot's power system, bird deterrent devices, as well as bird detection system (Figure 3). The system created did not run along the wire, therefore had no chance of coming into contact and harming ravens. Birdbox gathered data and tested the performance of the subsystems over time. The following subsections outline the steps followed in order to test the effectiveness of the artificial intelligence's ability to detect and deter birds. The "Birdbox" was deployed at the Rimmon Substation in Goffstown, NH and the checklist for this deployment can be found in Appendix II.

Birdbox consists of a webcam that has been placed to view a bowl filled with cat food as research shows cat food attracts ravens (Boarman, 2014). To test the deterrents, LEDs and speakers are mounted to the front of Birdbox allowing us to test the deterrents on Ravens as seen in Figure 4.

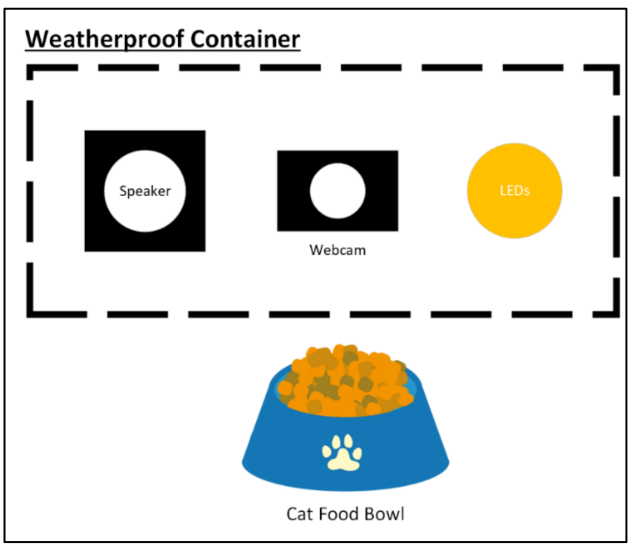

Figure 3: Birdbox Diagram

Figure 4: Completed Birdbox

4.1 Testing Rationale

Verified raven deterrents are required before finalizing the design of the robotic bird deterrent to ensure effectiveness. As stated in previous Sections, Birdbox and the Bird Deterrent Robot need to cause a bird to voluntarily leave the 20m x 20m area surrounding the device within 15 seconds. Also, no deterrent methods should harm the birds physically or use chemicals. For these reasons, Birdbox uses loud sounds from speakers and flashing lights from LEDS as non-dangerous deterrent methods.

The flashing LEDs and speakers from the previous prototype can be tested to determine the effectiveness of visual and audio deterrents. It was determined that the ravens react to the current deterrents. To test the AI bird detection, the false positive and negative rate were assessed by utilizing “realistic-fake” models of ravens before deployment.

4.2 Birdbox Hardware Specifications

Birdbox uses hardware currently on the Bird Deterrent Robot prototype. The various parts of each subsystem are listed below.

4.2.1 Power System

The power system will provide power to Birdbox remotely and freely. The power system includes the following:

- Battery: Provides 14.8V to the system.
- USB Splitter: Provides constant 5V to system and can be run on outlet provided by Eversource at the substation.
- Battery Charging Board: Controls the charging and output of the battery
- Power Monitor: LCD display to monitor the power output.
- Shunt: Creates a shunt that allows for power monitoring.
- E-stop: Emergency Stop to turn on and off the system

4.2.2 Boards and Controllers

The boards and controllers will provide the signals and communications necessary for the AI bird detection and bird deterrents. The boards and controllers include the following:

- Jetson: Utilized to process the AI Bird Detection and to communicate with the Arduino.
- Arduino: Communicates with and controls the deterrents.

- Mosfet: Used to toggle on and off the lights creating a strobing effect.
- Audio Board: Converts the audio file from the jetson to the necessary audio for the speaker output.
- Audio Converter: Creates a 3.5 mm connection from an HDMI connection on the jetson

4.2.3 Deterrents

The bird deterrent solutions will be used to interact with the birds and to achieve the success of causing the birds to fly away or flee the area when activated. The deterrent solutions include the following:

- LEDs: Series of LED lights that will flicker on and off as a strobe to visually deter birds.
- Speakers: one speaker that will emit an audio file that will audibly deter birds.

4.2.4 AI Bird Detection

The AI bird detection solution will be used to determine if there are birds present and to activate the deterrents to cause the birds to fly away or flee the area. The architecture of this system can be seen in Figure 5. The AI bird detection includes the following:

- Camera: The camera will be attached to detect the bird in the area.

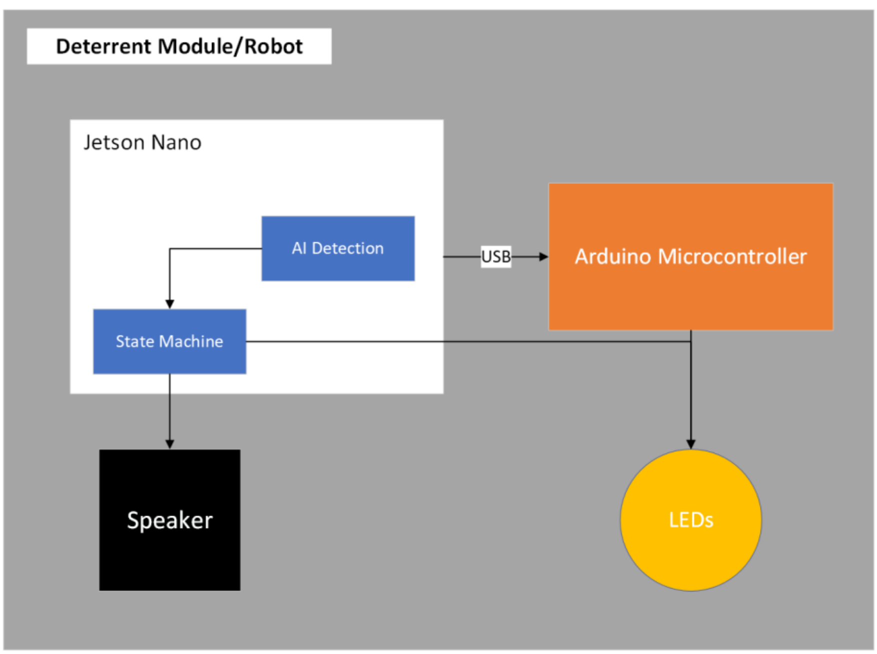

Figure 5: Birdbox Deterrent Module Architecture

4.2.5 Watchdog Camera System

The watchdog camera system will be utilized in Birdbox to determine bird presence, AI bird detection rates, deterrent activation, and deterrent success (Figure 6). This will run in parallel with the AI bird detection, recording avian response to the deterrent stimuli. The watchdog camera system includes the following:

- USB Webcam: Attached to the Pi for video collection
- Wi-Fi Hotspot: To monitor video live via an IP camera Stream
    - Future implementation
- Solar Power Bank: for power generator (if fully off grid)
- Extension cord: if "on grid"
- External USB hard drive: for video storage

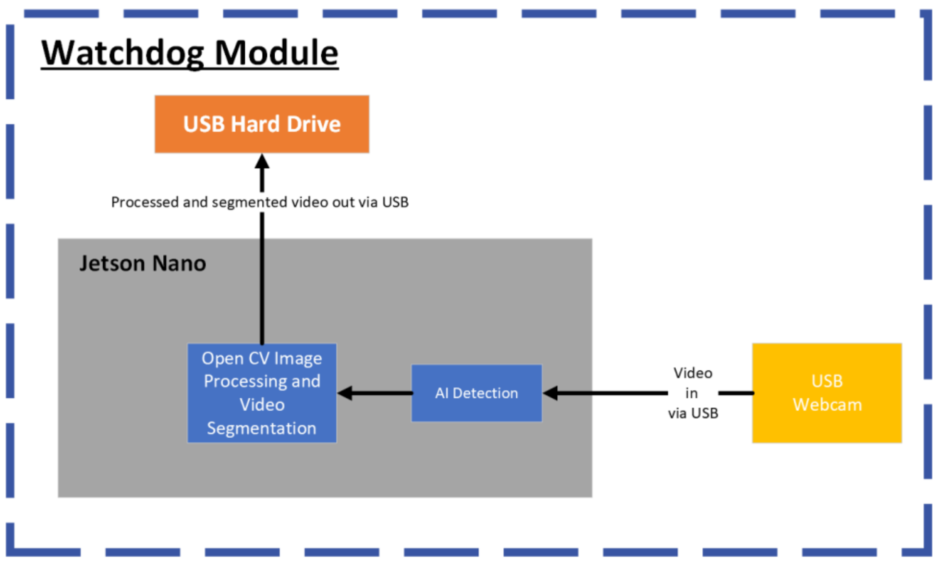

Figure 6: Birdbox Watchdog Module Architecture

4.3 AI/Watchdog Camera

The watchdog camera is a system integrated into Birdbox's state machine and runs in tandem with the AI detection on the Jetson. Using the frames captured for the AI, the watchdog camera saves 10 second segments of video at a time. If a bird is not detected in this 10 second interval, the recording is automatically deleted. Should a bird be detected in this segment, the recording continues, the deterrents are fired, and the bird's reaction to the stimuli is recorded for 10 seconds. This combined video containing both the bird's approach and reaction is saved onto a 512GB USB thumb drive. The watchdog camera continually checks the current capacity of the thumb drive to prevent overwriting existing videos. Additionally, the system utilizes a 1GB software buffer for a maximum size of 511GB of video data. See the architecture in Figure 7.

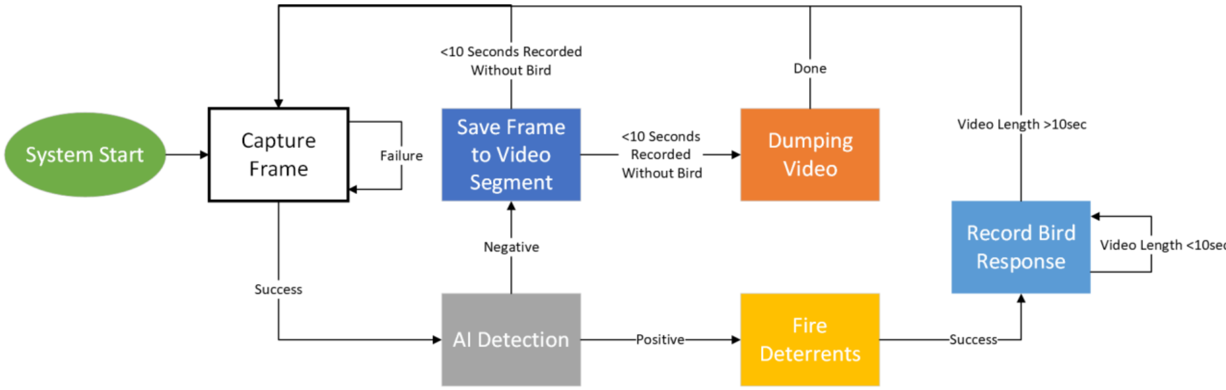

Figure 7: Watchdog Camera State Machine Diagram

4.4 Procedure

In order to test the AI detection algorithm, several tests were conducted prior to deployment to assess the false positive and negative rates for detecting ravens. The first test involved holding a model raven (dubbed "Ray") up to the camera and seeing if deterrents are fired within 5 seconds. This test was repeated 100 times, and the total number of failures will be the false negative rate. To assess the false positive rate, Birdbox was left undisturbed indoors where no birds can access the device. The watchdog camera module records a segment of video every time the AI detects a raven, so there would ideally be no videos on the hard drive after testing Birdbox in an area that is inaccessible to ravens. The system was intermittently shown the system black objects that might appear at the substation, such as work-boots and shadows. The video data after the test helped calculate the false positive rate.

4.5 Definition of Success

A success for the AI Bird detection solution is defined as the system properly responding to its respective camera feed. Failures of the AI system include not detecting a bird when present, not positively and accurately identifying a bird, and falsely identifying non-birds as birds. To determine the success rate of the AI bird detection, the video recorded from the watchdog camera system was compared against the reported successes of the AI detection.

Success for the communication between the AI bird detection and the bird deterrent solution is defined as the deterrents will be activated when the AI bird detection reports a positive detection.

To determine the success rate of the AI bird detection communication with the bird deterrents, the video recorded from the watchdog camera system was compared against the reported successes of the AI detection.

Success for the Bird Deterrent Robot is defined as the bird deterrent will cause the bird to fly away from the area. Success of the bird deterrents is defined as the ability to scare away the bird. In future testing, success will ideally be redefined as causing the bird to fly away not return, but also as the repeatability of causing the bird to flee if it does return. To determine the success rate of the bird deterrent solution, the video recorded from the watchdog camera was compared against the reported activation of the bird deterrents.

4.6 Birdbox Implementation and Results

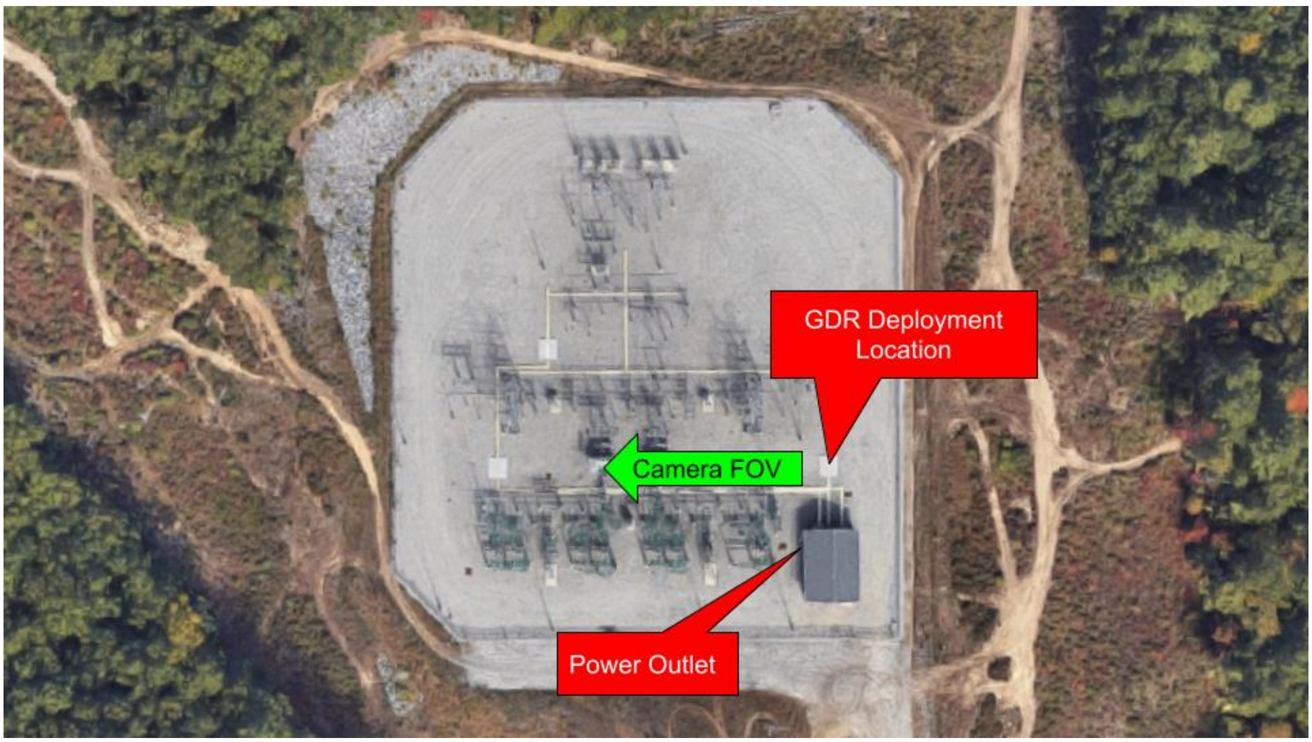

Figure 8: Substation Birdbox Deployment

The team deployed Birdbox in the morning by connecting the system to a power outlet located at the substation via an extension cord. Figure 8 depicts a visual of the layout of the deployment location. Deployment required a few team members to enter the substation with the proper personal protective equipment (PPE). Individuals entering the substation fence were required to wear a flame-retardant jumpsuit, protective boots, safety goggles, and a hard hat. Please refer to

Appendix II: Checklist for Birdbox Deployment to ensure all components, supplies and protective equipment that might possibly be needed are brought to substation.

Birdbox was deployed outdoors for a total of 25 days, some of which included extreme weather such as a winter storm with wind, snow, and rain. Upon retrieval, the team noticed that there was no sign of weather-related damage. There was no water inside the box, silicon sealant remained intact, components did not suffer from water damage, and remained functional after their retrieval. It was found that the watchdog camera was also successful: it recorded video before and after the AI returned a positive result and saved the video with a time stamp to the onboard USB drive, and deterrents successfully fired every time. The system successfully went into sleep mode after 5pm and before 8am to avoid disturbing nearby residents and operating during hours with suboptimal lighting.

Unfortunately, due to a fault in the AI model, none of the footage Birdbox captured contained ravens or raven activity. This fault caused the AI to constantly return positive results, thus repeatedly firing the deterrents and saving video. This caused the USB drive to fill up after about two days of operation. Using the images captured, the AI model was retrained with the images taken from the substation to mitigate false positives. Furthermore, new photos of ravens in different weather and lighting conditions to ensure this issue would not persist in a future deployment.

5.0 Design and Development

This Section will outline the team's design for the Bird Deterrent Robot that will allow us to fulfill the requirements discussed in Section 3.0 Project Needs and Requirements.

5.1 Deterrents

Variability is critical when deterring ravens. Ravens are highly intelligent creatures with the ability to adapt quickly to their surroundings. To combat raven adaptation, a series of deterrents with the ability to control outputs and modify deterrent features were used. The robot includes visual and auditory deterrents. For visual deterrents, multiple LED strobing lights were incorporated into the system. For auditory deterrents a series of speakers located around the robot were used.

The LED Panels on the robot are controlled by the Arduino using a switching circuit used a MOSFET. This was done to have a controllable switching feature where the frequency of the LED strobing could be changed to improve variability.

Four speakers were mounted on the robot to broadcast a 4000 Hz signal noise. The speakers are connected to an audio board to allow for addressable stereo sound. This enabled us to control which direction of speakers would play the audio files. The speakers are able to play different sound files located on the Jetson to allow for increased variability.

5.2 ToF Sensors

To improve bird safety and read distance, laser Time of Flight (ToF) distance sensors were used. ToF sensors were chosen because they take up very little space, draw minimal amounts of power and can differentiate objects. The Adafruit VL53L0X ToF sensors can see up to 2 meters which is enough range to detect, slow down, and stop in front of a bird. Furthermore, the Adafruit sensor has a smaller software library than the previous sensors, which is better implemented with the Arduino board.

5.3 State Machine

The primary detection and deterring methods of the robot are controlled by a state machine. The camera and ToF sensors take in raven specific data and relay it to the state machine that then interprets this data and enacts one to two possible states: patrolling and detecting. While the robot traverses the transmission line, the AI searches for ravens using the input of the camera module. If the AI detects a raven, the state machine initiates a “stop robot” protocol, bringing the device to a complete stop. Upon stopping, the state machine shifts into a “deter” state which calls the LEDs to flash and for the speakers to produce beeps at 4000Hz. These deterrent methods are active until the AI can no longer detect a raven on the transmission line. It is crucial to note that in an occasion where the AI fails to detect a raven, the ToF sensors were calibrated to detect ravens based on proximity to the sensor(s). This distance is 0.5 meters such that the robot can come to a complete stop before making contact with the raven. If a ToF sensor is activated, the state machine enacts the same “deterring” methodology as stated above. The aforementioned state machine is described in Figure 9.

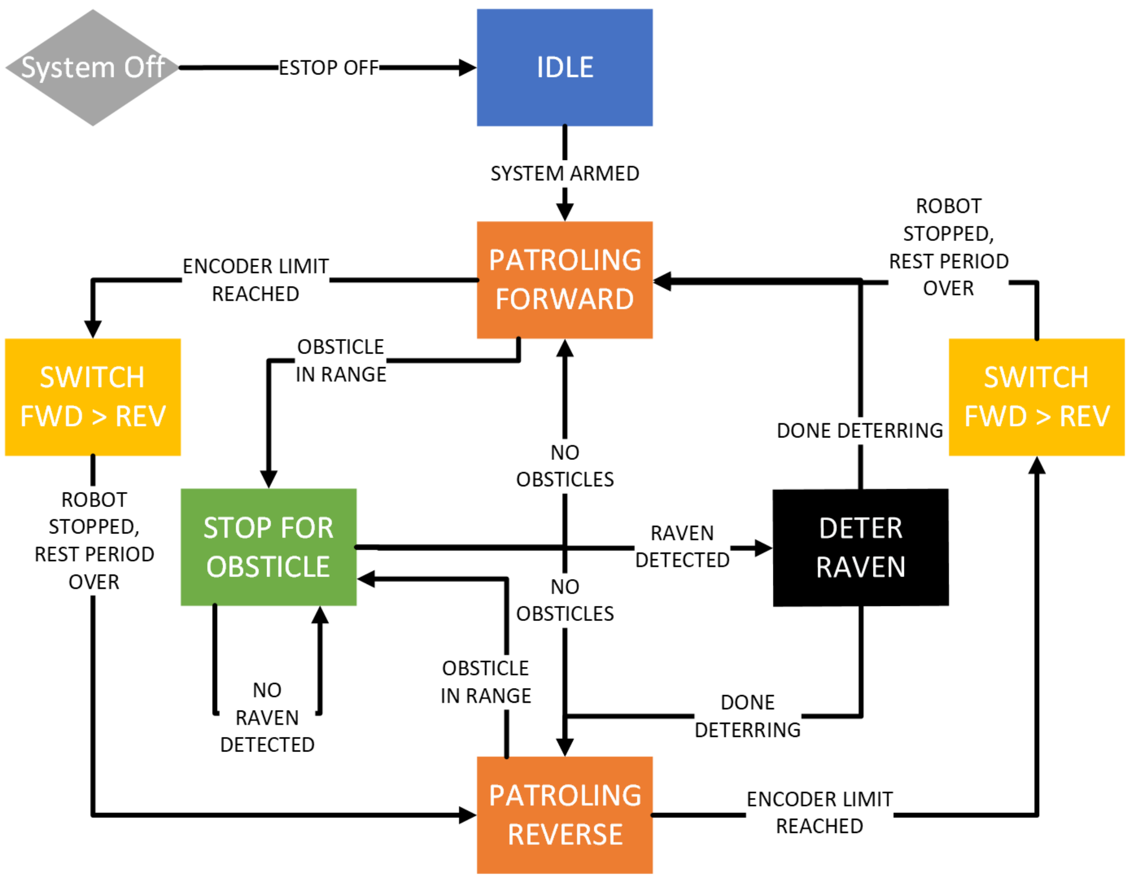

Figure 9: State Interaction Diagram

5.4 Spire

The Spire, or uppermost enclosure on the robot, mounts all of the electrical components, connections, and motherboards to the robot. Figure 10 highlights critical design considerations for this apparatus:

Spire Design Considerations	
1.	Enclose all detection and deterrent hardware(s).
2.	Provide an IP 67 weatherproofed system.
3.	Facilitate power delivery connections.

Figure 10: Spire Design Considerations

5.4.1 Spire Design and Fabrication Process

The Spire must house all the electrical components that facilitate raven detection and raven deterring methods. Figure 11 illustrates all the components that must fit within the Spire:

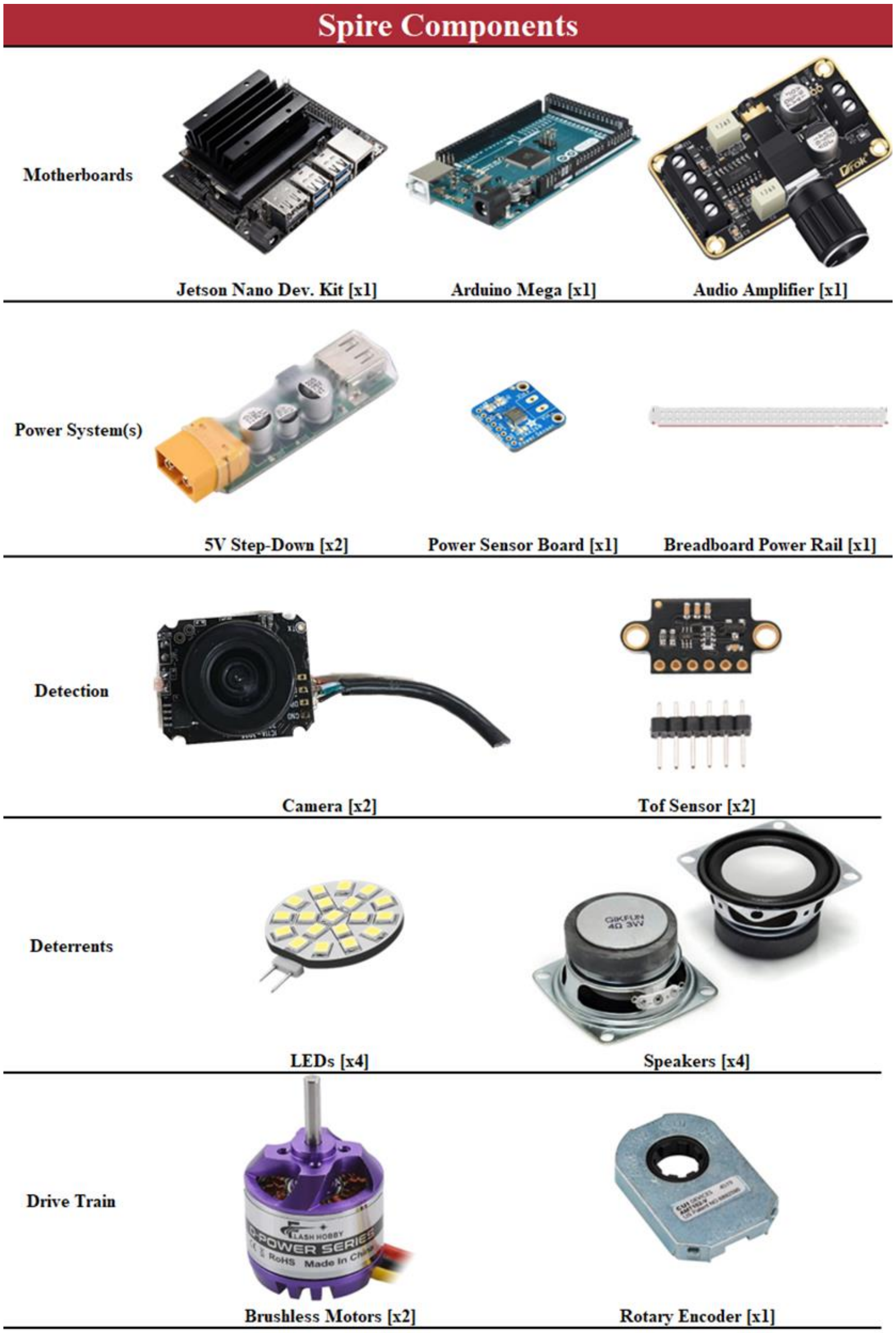

Figure 11: Spire Component List

*It is key to note that there are components that are mounted to the robot outside of the Spire but must have access to the motherboards.

The Spire fabrication process was comprised of two distinct features: pre-made components and 3D-Printed parts. The Spire enclosure's exterior covering is a Rubbermaid clear plastic food storage container. The components are housed within was chosen for the container's waterproof nature as well as its volume. The pre-made container offered the volume required to house all the electrical components as well as extra space for any future additions to the system. Furthermore, the Rubbermaid enclosure had a rubber gasket and clip system that proved to be both waterproof and weatherproof. Other pre-made components within this design include hardware, such as screws, bolts, and wire glands.

The majority of the components within the Spire were modeled in SOLIDWORKS and fabricated using 3D-printers. In order to optimize the volume offered by the pre-made enclosure, many parts required custom made components. The parts modeled are in Figure 12 as follows:

Custom Spire Components	
1.	Spire Bottom Mounting Plate
2.	Spire Collinear Module
3.	Spire Perpendicular Module
4.	Arduino Mega "Shelf"
5.	Spire to Robot Mounting Bracket

Figure 12: List of Custom Spire Components

* All CAD files will be available upon request to the following email address: gr-birddeterrant-all@wpi.edu.

The Spire bottom mounting plate serves as the primary mounting location for all of the electrical components. The plate was designed to offer locations for threaded heat inserts to facilitate mounting the required components, as well as recesses for the wire glands (a waterproof solution for feeding wires through any enclosure). The plate has a variety of mounting holes to accommodate movement of parts and future expansion. This part was mounted in the lid of the Rubbermaid. In order to secure all the electrical components this bottom mounting plate must sit as flush with the Tupperware lid as possible. Thus, this part also has cut-outs for hinge clearance to ensure it sits flush with the lid. Please refer to Figure 13 for a visual representation of this part.

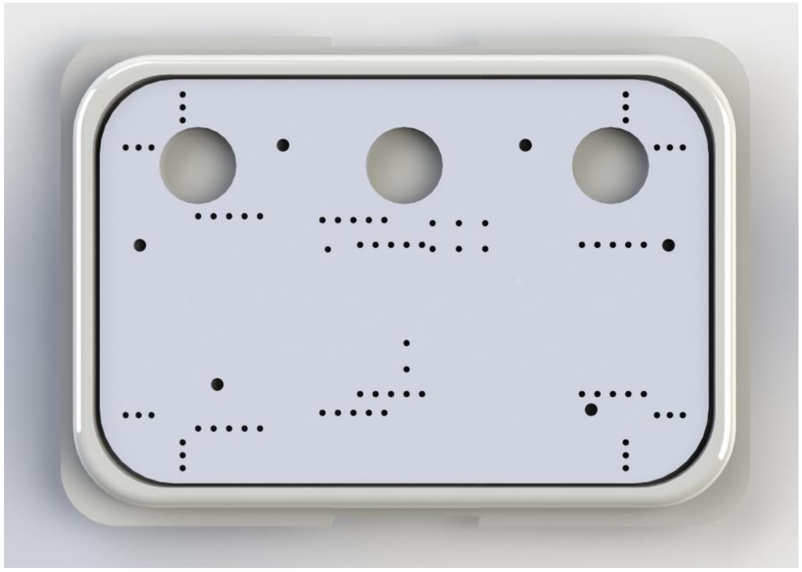

Figure 13: Spire Bottom Mounting Plate

The Collinear mount held the camera, two LEDs, and 5V step-down, and ToF sensor in one compact footprint. By grouping these components together, this design was able to utilize more volume of the Spire enclosure. Specifically, this module mounts the ToF sensors and camera collinear to the transmission line to facilitate detection as previously mentioned. This module clamps the LEDs in place with a clam shell design as well as aligns the LEDs collinear with the wire to aid in deterring any detected ravens. The 5V step-down was placed below the camera module as a way to secure its position within the enclosure. Securing each component is crucial, as loose components may create weak connections, or if dislodged can dislodge other components from their respective locations. Please refer to Figure 14 for a visual depiction of the component.

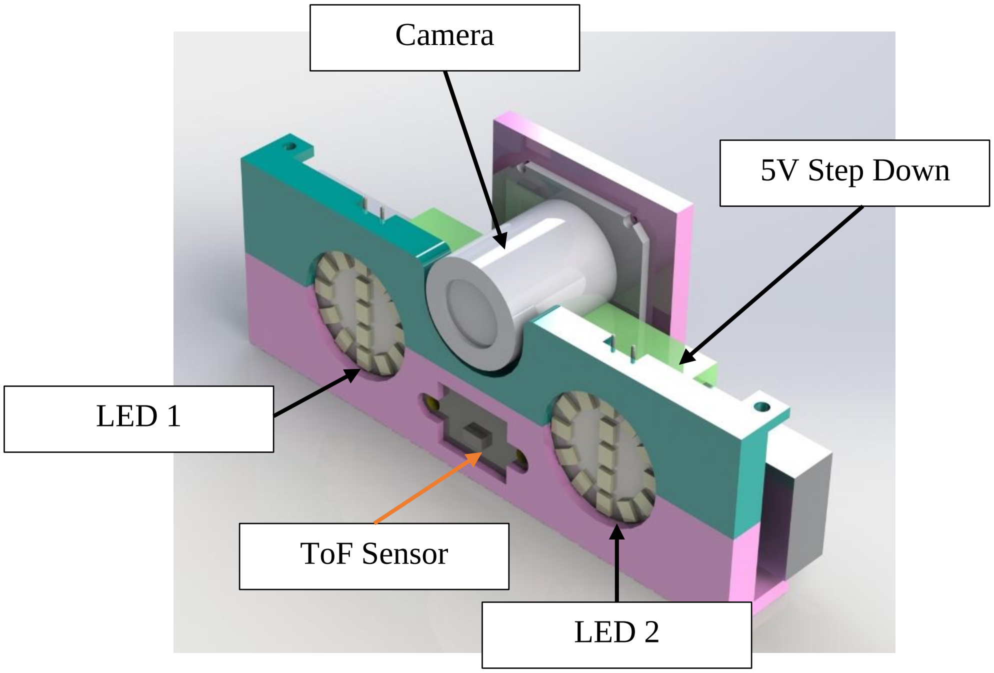

Figure 14: Collinear Camera, ToF, LED, and 5V Step-Down Module

Similar to the above module, the perpendicular module only houses LEDs. The perpendicular mounts aim to house a create quantity of LED's in the system to aid in deterring. Cameras and ToF sensors were not required on the sides of the enclosure perpendicular to the transmission wire as the AI is not built to detect incoming ravens, rather ravens currently on the wire, or collinear with the Spire. Please refer to Figure 15 for a visual representation of this design.

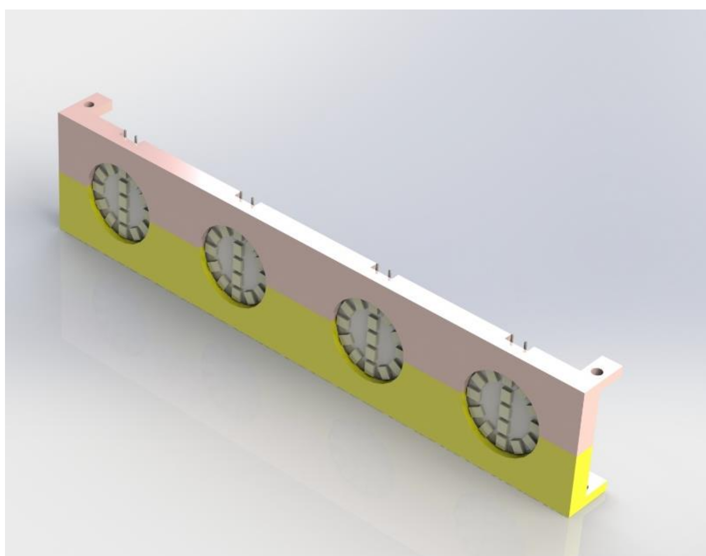

Figure 15: Perpendicular Camera, ToF, LED, and 5V Step-Down Module

The last component within the Spire was the Arduino shelf. This part serves as a custom "hat" for the Arduino motherboard. This shelf gives new surface area to mount the audio board and power sensor without worry that the bare connections may short something within the system. The shelf itself has cut-outs around the pin headers so that they are still accessible for the appropriate wiring. The shelf also has mounting holes for the associated mother boards and long slots to help with airflow. Please refer to Figure 16 for a visual depiction of the layout and features of this design.

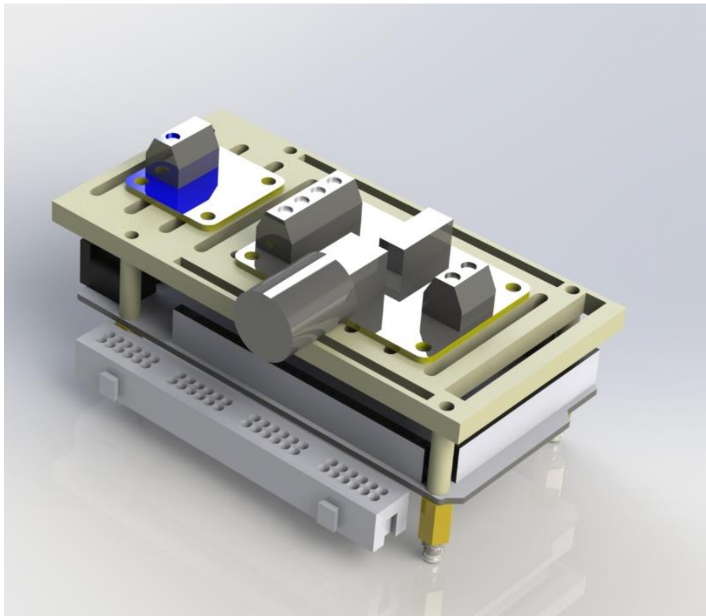

Figure 16: Arduino Shelf Assembly

In order to mount the whole Spire enclosure to the robot, the Spire mounting bracket was designed. This component uses five M5 screws with O-rings to adhere the mounting bracket to the bottom mounting plate. These O-rings created a weatherproof seal and ensured that moisture does not enter the enclosure and damage the electrical components. Furthermore, sheet metal screws were used to mount the bottom mounting plate to the robot itself. Please refer to Figure

17 for a visual of this part. Additionally, please refer to Figure 18 for a visual representation of the interfacing between the Spire bottom plate, Spire lid, Spire mounting bracket, and the robot.

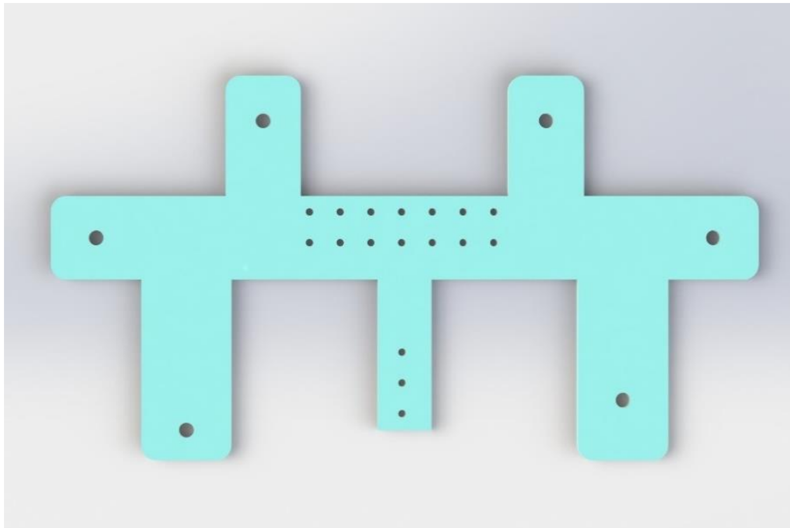

Figure 17: Spire Mounting Bracket

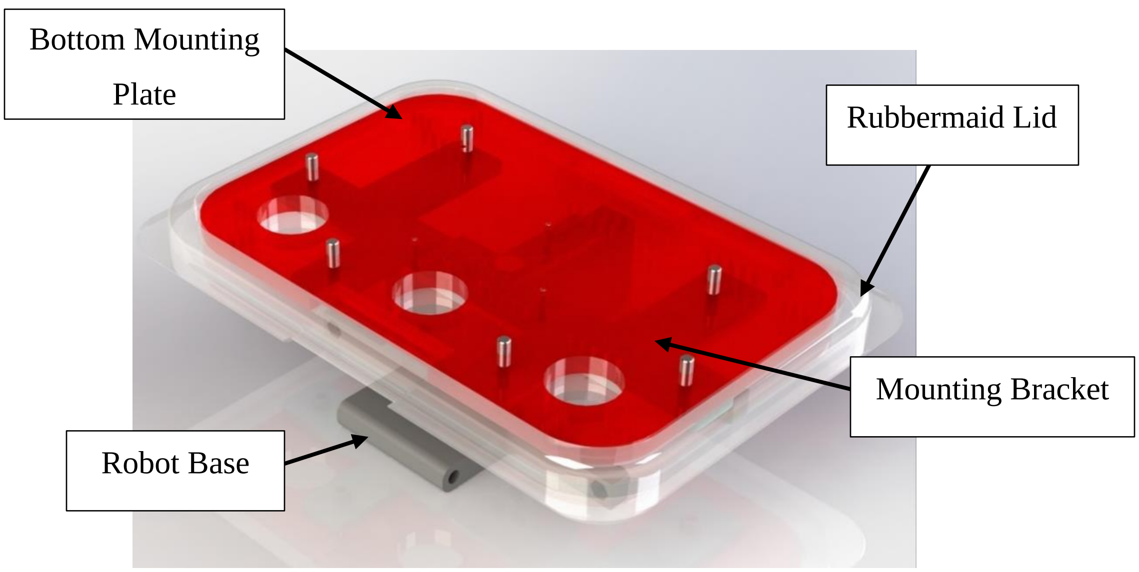

Figure 18: Interfacing between Spire Bottom Plate and Mounting Bracket

Once all of these components and parts were assembled, they produced the Spire Assembly. Please see Figure 19 for a visual of the final apparatus.

Figure 19: Final Spire Assembly

5.4.2 Spire Implementation

A primary concern for the Spire enclosure is the center of mass in reference to both the transmission line and the robotic system. For the spring-loaded wire clamp to function properly, the center of mass of the robot must be centered with the epicenter of the transmission line as well as below the wire clamp system. Maintaining a center of mass below the transmission line allows the weight of the system to fully engage the spring-loaded wire clamp system, which in turns facilitates smoother movement of the system across the wire.

To facilitate the above-described state, the Spire must have its center of mass directly above the epicenter of the transmission line and maintain the majority of the weight of the system as close to the transmission line as possible. In the most ideal scenario, the weight of the Spire would be below the transmission wire. However, the drive train model from the previous team did not allow for the mounting of the Spire below the transmission line. Therefore, the weight of the Spire was kept as close to the transmission line as possible.

With the weight of the Spire being above the transmission line rather than below, the Spire unit creates a top heavy system. By introducing weight at the top of the system, the robot becomes prone to rotation while on the wire. Failure could occur if the robot rotates upside down on the wire as this would disengage the drive train. To avoid this, the weight of the Spire must be as close to the transmission line as possible. Furthermore, the battery compartment (elaborated in the following Section) was lowered from the transmission line to serve as a counterweight to the top heavy Spire.

The Spire, after fabrication and assembly, was able to maintain the desired center of mass. Please refer to Figure 20 for a visual representation of the Spire's center of mass.

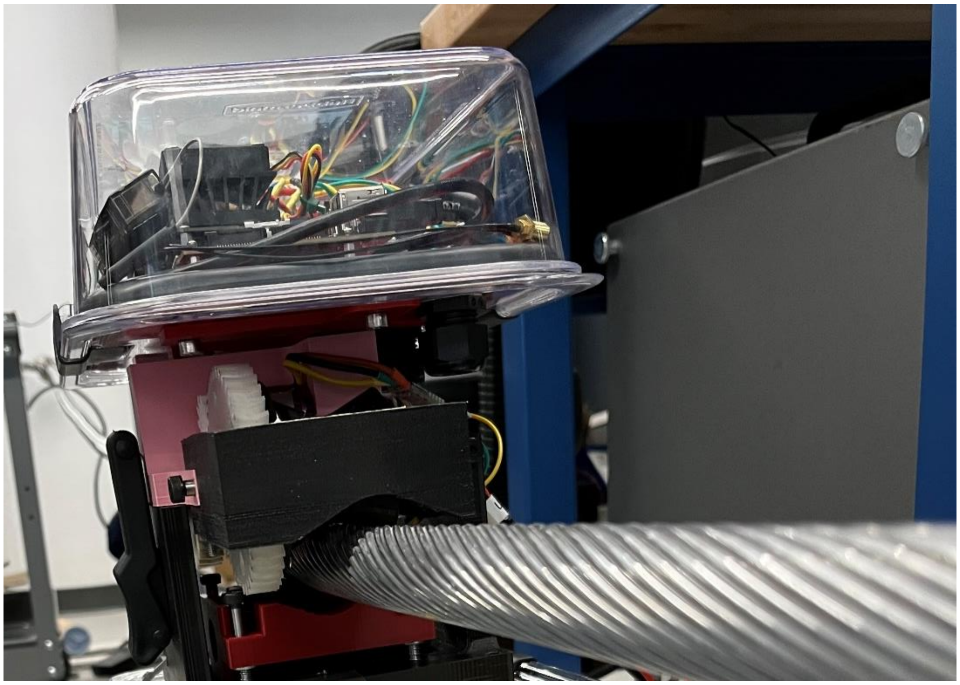

Figure 20: Spire Center of Mass

5.5 Battery Compartment

The battery compartment is the power compartment located at the base of the robot as seen in Figure 21. This compartment provides mounting for each of the supporting power components including the robot's power level display, emergency stop button, power supply battery, recharge circuit board, shunt, and wireless charging receiver. Placing all the power equipment in one container allows for short connections between components in this subsection while also providing the minimal number of external connections being a single regulated power cable.

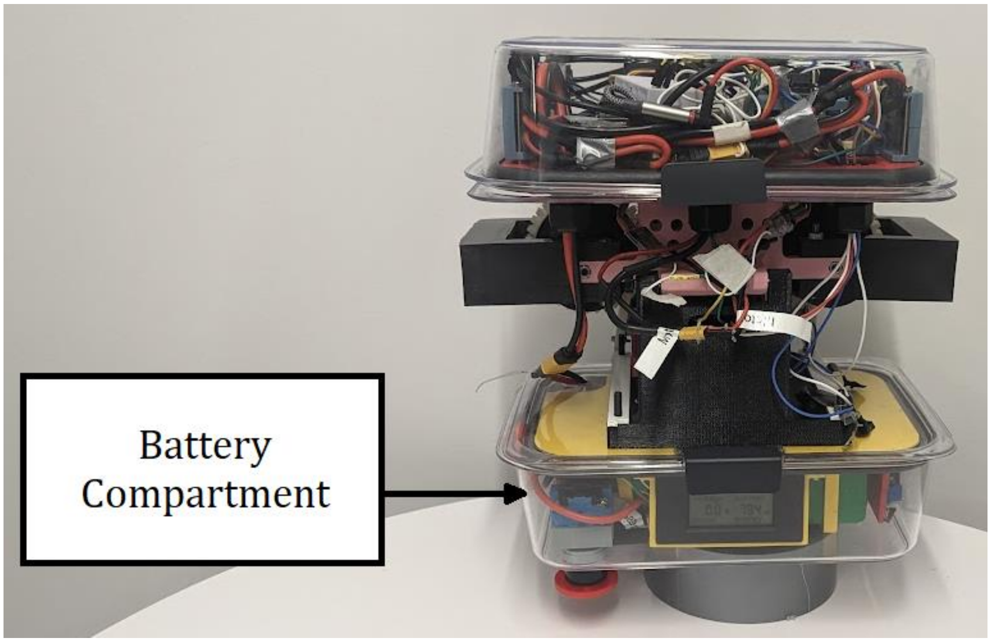

Figure 21: Battery Compartment (mounted to robot)

5.5.1 Battery Compartment Design

The enclosure design uses similar components to the Spire such as using a Rubbermaid container as a housing, a 3D printed PLA mounting plate with brackets, and a submersible cord grip for an electrical port. The mounting plate, as seen in Figure 22, has holes for threaded heat inserts to provide screw mounting points for the 3D printed brackets. Multiple small, raised surfaces allow for the charging board to be located underneath the battery. Extra space is included underneath the battery in case additional cable management is desired in the future.

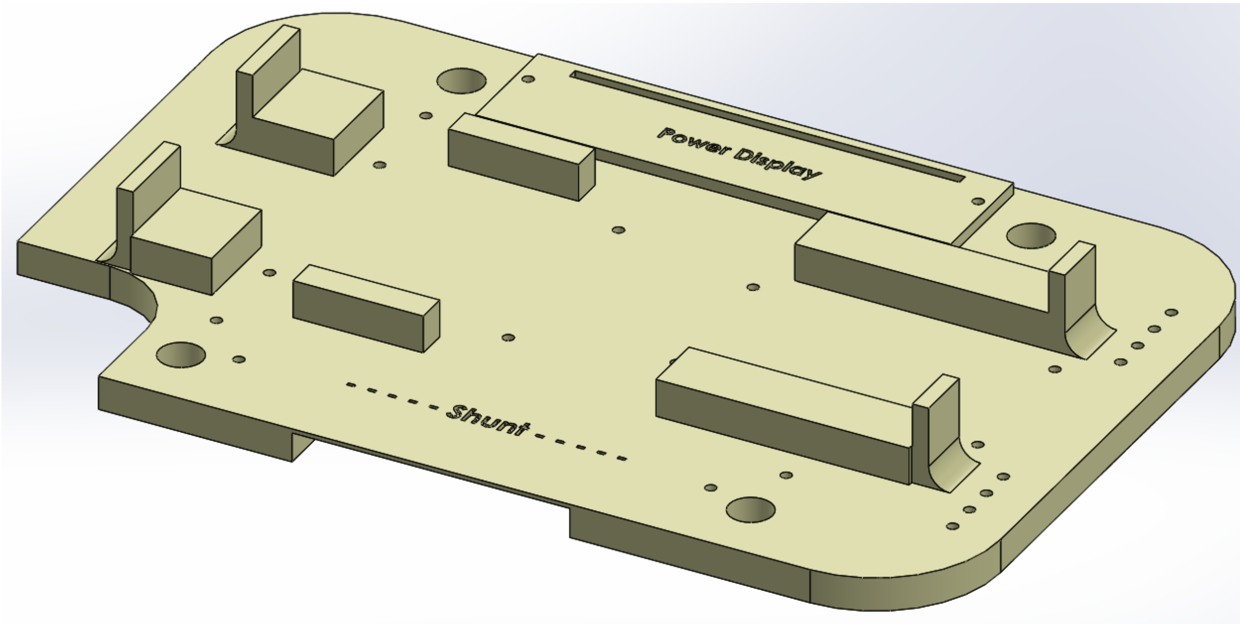

Figure 22: Battery Compartment Mounting Plate

The shunt is an electrical component that aids in monitoring the current of a battery. This component is entirely metal and should be insulated. A cover was 3D printed in PLA to prevent the shunt from encountering other electrical components as seen in Figure 23. This cover includes two M2.5 mounting holes for affixing. Two large openings provide a path for the high-power electrical wires while three smaller openings provide a path for the smaller sensing wires.

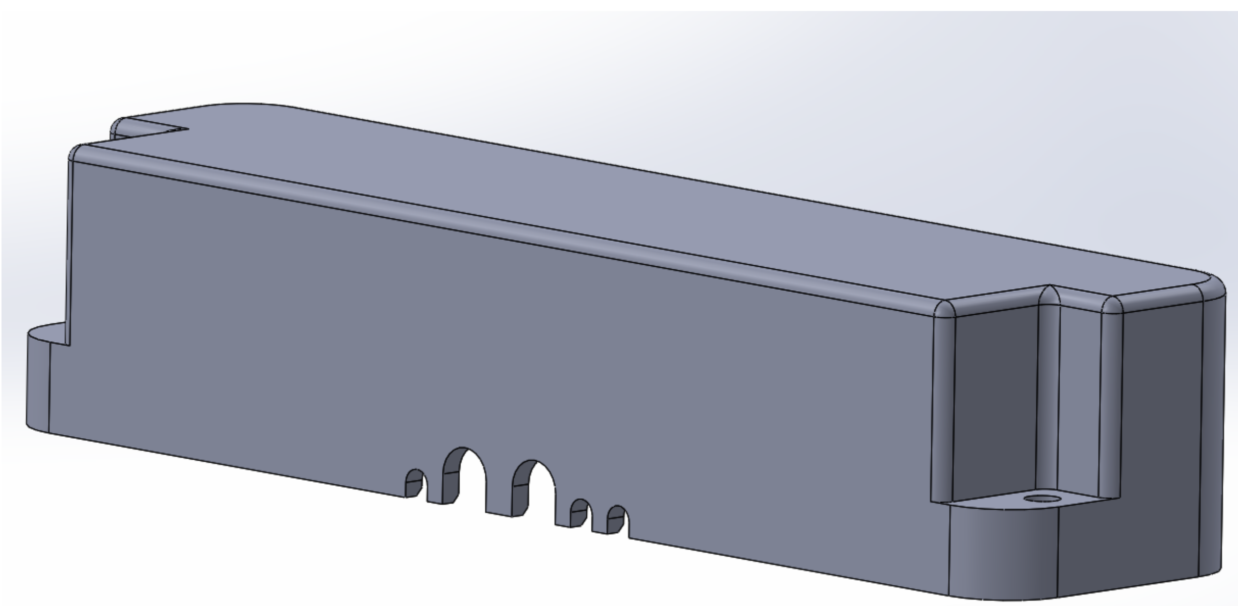

Figure 23: Battery Compartment Shunt Model

The wireless charging receiver's coil has a diameter larger than the height of the enclosure. Bending the coil to conform to the side of the enclosure was unideal as it would diminish the effectiveness of the coil. As such, the coil is located on the top of the enclosure to provide the coil with a surface to mate with the pairing transmitting coil, Figure 24.

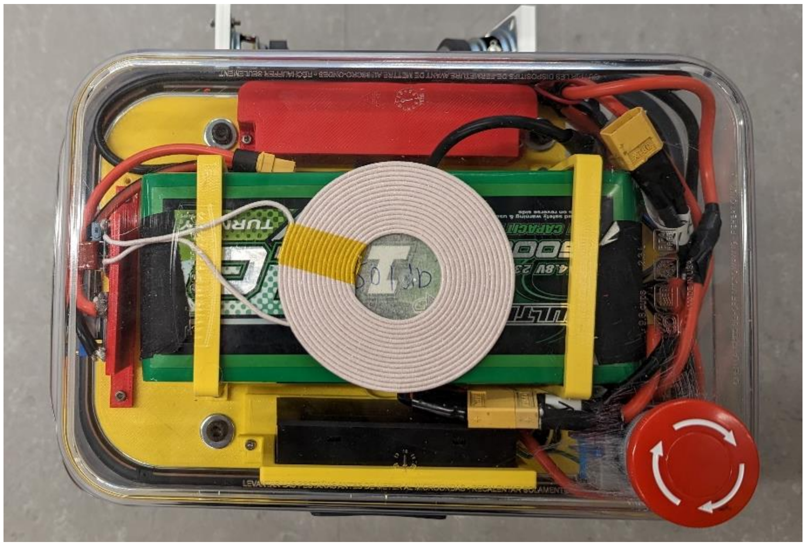

Figure 24: Charging Coil within Battery Compartment

This housing compartment was able to contain all the necessary components. With onboard power, the robot is able to traverse the wire untethered until it needs to recharge.

5.6 Housing Weatherproofing

The weather provided hazards for the robot. Precipitation and humidity can cause electrical components to malfunction or fail. PLA, the filament used to produce these components is subject to dissolving when exposed to wet conditions. These weather conditions concerned the safety of the robot and were addressed in the following ways.

The Spire and battery compartment protected its electrical components through a variety of methods. The plastic enclosure acts as a barrier between the external weather and the internal components. Submersible cord grips in conjunction with cables were used to provide sealed electrical ports through the enclosure Figure 25. For the Spire, these ports allowed electrical power and wheel encoder data to be fed into the Spire and allowed amplified audio and motor signals to be transmitted to the external components. For the battery compartment only one port was needed to provide power to the Spire. Utilizing wireless charging in the battery compartment provided a connectionless method of recharging the robot, preventing the need for weatherproofing charging connections.

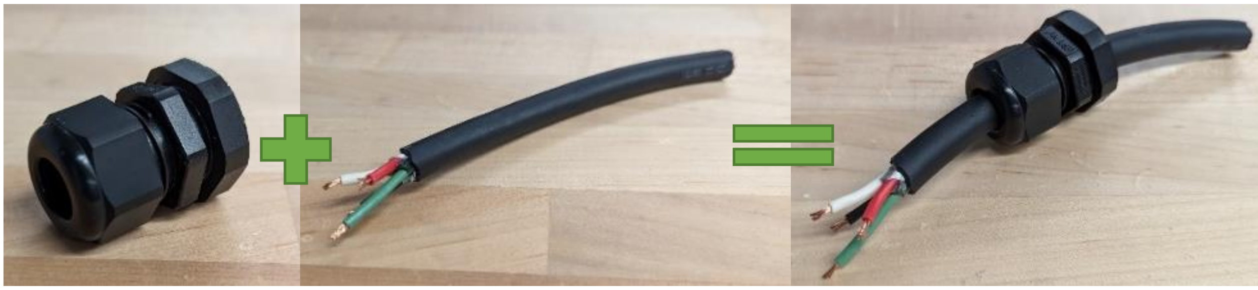

Figure 25: Cord Grip Assembly

Stainless steel fasteners were used on exposed connection to secure parts of the robot together while minimizing the effectiveness of water rusting components which would lead them to fail. M5 socket head screws and M5 nylon lock nuts form the basis for structural connections on the robot, while M2.5 socket head screws and M2.5 threaded heat inserts are used to secure small electrical components. Sealing screws were intended to provide a sealed mechanical connection through the plastic enclosure to the rest of the robot.

6.0 User Experience/Mobile Application

To allow Eversource officials to operate the robot in a user-friendly manner, a ReactJS web app that communicates with the system in real time was created. Officials can use this app to view data or send commands to the robot. The app sends and receives data from a Flask web server, utilizing JSON files that are parsed for the end user. Figure 26 shows the architecture of the mobile app communication protocol.

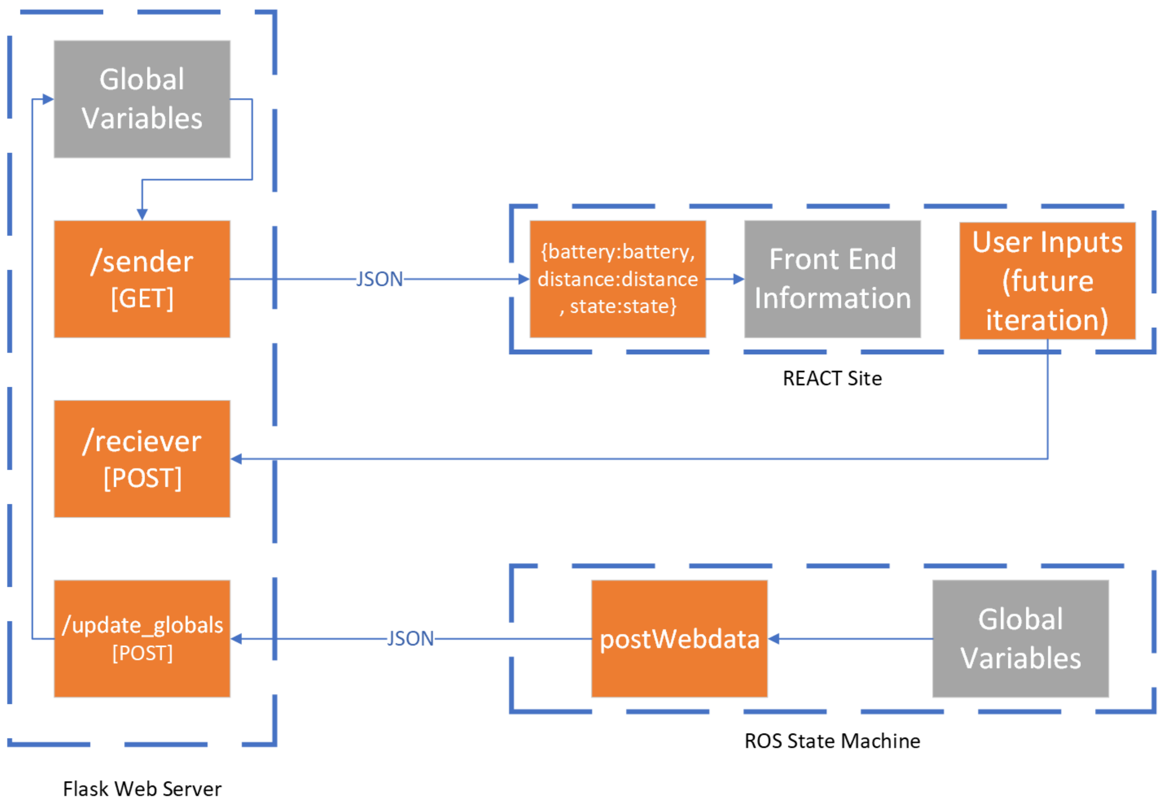

Figure 26: Web Communication Diagram

The end user can easily view the robot's current state, battery capacity, or location on the wire. The application will relay information via a mobile hotspot on the robot which bypasses the range constraints of the radio controller. The mobile hotspot allows for the control or monitoring of the robot from anywhere at any time (Figure 27).

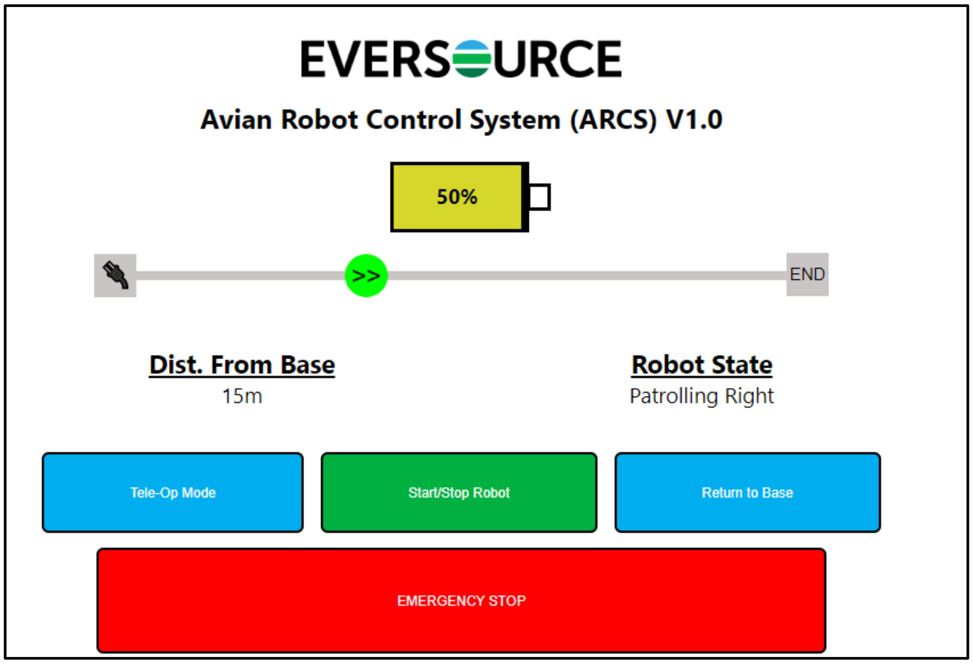

Figure 27: Mobile App, Robot Patrolling Right

Figure 28 demonstrates the mobile application’s home screen and Figure 28: Respective Icons by Robot State shows applicable status icons.

State	Respective Icon	Icon Purpose
Patrolling Right	>>	Indicates the robot moving right
Patrolling Left	<<	Indicates the robot moving left
Alert/Obstacle Detected	!!!	Indicates the robot has detected a non-raven obsticle
Raven Detected		Indicates the robot has detected a raven
Idle		Indicates the robot is idle
Charging		Indicates the robot is charging
Disconnected		Indicates the mobile app is not connected to the robot

Figure 28: Respective Icons by Robot State

7.0 Docking Charging Station

The purpose of the docking station is to provide the power supply battery on the line deployable robot with a source of battery charging. The robot will be able to intermittently return to the docking station while on a transmission line. Intermittent charging is necessary since the robot is expected to be active during raven active times, yet the power supply battery's capacity is not large enough to allow for this. A docking station provides a place for the robot to return to replenish the battery when it is low (Figure 29).

Figure 29: Mock Docking Station

7.1 Changes to Docking Station

The original design for the docking charging station included a wire clamp, hinge, and an exposed main body. The main body of the station featured two charging plates that used physical conduction with magnetic pins to charge the LiPo battery through the Battery Management System. However, this charging method led to a significant risk of electrical shorting if the docking station was exposed to water. Not only were the electronic components of the station exposed, but the charging plates themselves were also susceptible to short-circuiting, which could potentially result in irreversible damage.

To mitigate this risk and align the docking station with the project requirements, it was necessary to re-design the charging system to make it IP67 resistant. The new design includes a weatherproof housing for the main body. In addition, the physical conduction charging method was replaced with an inductive charging method, which uses electromagnetic induction to charge the battery without requiring physical contact between the charging station and the robot. This new design significantly reduces the risk of electrical shorting and damage to the charging station, even in wet environments. It also prevents dust and other external particles from entering the enclosure and damaging electrical components.

7.2 Charging System Architecture

The updated charging system architecture is as shown in Figure 30. The power supply battery is the main power source for the line deployable Bird Deterrent Robot and powers all of its electrical components. To charge the power supply battery, a solar panel will harvest solar energy and convert it to electrical energy. The solar panel connects to a MPPT solar charge controller for a 11.1V 3S LiPo battery. The battery is also in parallel with a Qi-wireless transmitter coil. The transmitter coil will transfer energy from the battery to a Qi-wireless receiver on the base of the line deployable robot, where it is converted back into electrical charge. The voltage must be boosted to provide an adequate potential difference for the protection circuit module (PCM) to charge the power supply battery.

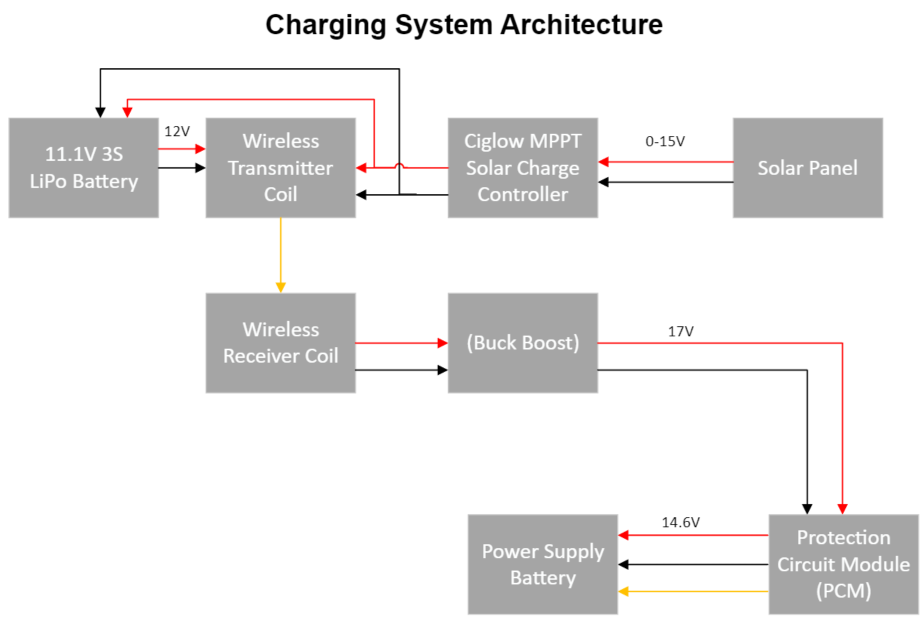

Figure 30: Charging System Architecture

7.3 Solar Energy

The charging dock uses a renewable solar energy source to replenish its supply of charge to the robot. The power source provided to the 11.1V storage battery in the docking station must be renewable, as electrical outlets would not be applicable for a transmission line located above Cedar Pond. A solar panel of at least 300W should be installed with the charging dock to provide enough energy for the robot. The estimated power usage of the line deployable robot is as follows: 7.5W idle, 14W patrolling and 28W actively deterring. This leads to a total approximate energy consumption of about 183Wh per day. As the ravens are only active during the morning hours of the day, these energy estimations are based on 8 hours of patrolling, 2 hours of actively deterring and 2 hours of idling. However, since Qi-wireless charging is 85% efficient, the total energy consumption per day is estimated to 210Wh.

A peak sun hour is defined as an hour in the day when the intensity of the sunlight reaches an average of 1000 watts per square meter. A solar panel is not considered to be fully active unless during peak sun hours. New Hampshire receives about 4.61 peak sun hours per day, with summer peak sun hours up to 5.3 hours per day and winter peak sun hours up 3.66 hours per day. On sunny days, a 70W solar panel will theoretically suffice. However, not every day is sunny and solar panels should be considered at 25% efficiency. Therefore, a solar panel of at least

300W should be considered. A downside of a 300W solar panel requirement is that the average size is 36 inches by 65 inches. They are large enough to be considered for home use and are generally not sold individually. In addition, the price per 300W solar panel is about $300. For testing purposes, a 15W solar panel will be used as proof of concept.

7.4 Solar Charge Controller

The solar panel will be powering the electronics required to charge a 11.1V LiPo storage battery in the docking station. The Ciglow MPPT-V08A Lithium Solar Charge Controller, which is a maximum point power transfer solar charger, is used to improve the efficiency of the power delivered from the solar panel to the storage battery. In a typical solar panel system, the voltage of the panel tends to fluctuate depending on sunlight levels. As the amount of sunlight increases, the voltage of the panel also increases, potentially leading to overcharging the battery if not regulated properly. An MPPT solar charger works to continuously monitor the power output of the solar panel and adjust the charging current to maintain the optimal charging voltage for the battery. The charger does this by finding the maximum power point of the solar panel. The charger then adjusts the charging current to maintain optimal charging voltage for the battery, meaning the voltage will stay constant even with a fluctuating power output. By preventing the voltage from collapsing, the MPPT solar charger extends the life of the battery and prevents damage from overcharging. Originally, the Sparkfun LT3652 Sunny Buddy was considered for this role, however, the output load voltage produced by the Sunny Buddy was not enough for the wireless transmitter. The instructions for setting up the Ciglow MPPT Solar Charge Controller are found on Robot Zero One’s website.

7.5 Qi-wireless Charging Standard

Our design follows the Qi-wireless charging standard, allowing the line deployable robot to be wirelessly charged from the fixed docking station on one end of the transmission line. Section 7.1 Changes to Docking Station highlights the design benefits of wireless inductive charging to fit with the weatherproofing requirements. The decision to follow the Qi-wireless standard for charging the robot offers significant benefits in terms of compatibility, efficiency, and power consumption. One of the key benefits of following the Qi-wireless standard is its wide compatibility. Any Qi-wireless receiver module can receive power from any Qi-wireless transmitter module, making it an industry-standard wireless charging method. Additionally, Qi-wireless charging offers up to 85% efficiency up to 1.4 inches, despite any power loss caused by heat, interference, and internal resistances. Finally, Qi-wireless chargers consume a negligible amount of power while not charging a load, which is important to prevent draining the docking station's precious solar power. The transmitter and receiver modules on the robot are from Taidacent and are rated for 12V and 2.5A. These high-power long-distance charging modules could supply the power supply with more than the approximate 20W of it power it needs to charge at 1A.

7.6 Power Supply

The Protection Circuit Module (PCM) currently on the robot serves to optimize charging of the power supply battery on the robot. The PCM design has been kept from last year’s robot design. In order for the supply battery to charge, a potential difference of greater than 15V must be supplied to the PCM. The output of the Qi-wireless charging receiver module only supplies a 12V potential difference. Therefore, a buck-boost voltage converter from dkplnt is used to boost the voltage given to the PCM. The buck-boost converter has a boost efficiency of 94% due to its high efficiency MOSFET switches. Currently, this voltage is boosted to 17V, however, it may be changed to any potential difference between 5V and 35V.

8.0 Results & Testing

After implementing the aforementioned sensors, code, and communication methodologies, a series of test scenarios were created. Each of these scenarios aimed to test a different system within the robot. The following Section outlines the methods, processes, and results of these test cases.

8.1 Waterproof Testing

Given that 3D printed components need to be weatherproofed, the team tested ways to protect PLA components. To test the effectiveness of a common waterproofing method, an experiment was conducted utilizing acrylic spray. Acrylic spray, depicted in Figure 31, is commonly used to protect patio furniture. A total of four identical PLA pieces were used in the experiment, two of which were treated with acrylic sealant. One treated, and one untreated piece were left under a running showerhead for two hours to simulate rainfall, and an additional treated and untreated piece were left exposed to the air as a control group. These parts were weighed before and after the two hours of respective exposure to air and water.

Figure 31: Acrylic Spray (gorillatough.com, 4/23/2023)

It was discovered that the acrylic sealant used was effective in protecting PLA components. The treated piece left under running water collected an additional 0.5g of water, whereas the treated piece gained none. Figure 32 provides a visual of the observed relationships between weight of each component over time. The untreated piece was visibly leaking water after the experiment concluded. The control pieces left exposed to air did not have detectable change in weights after the two hours concluded.

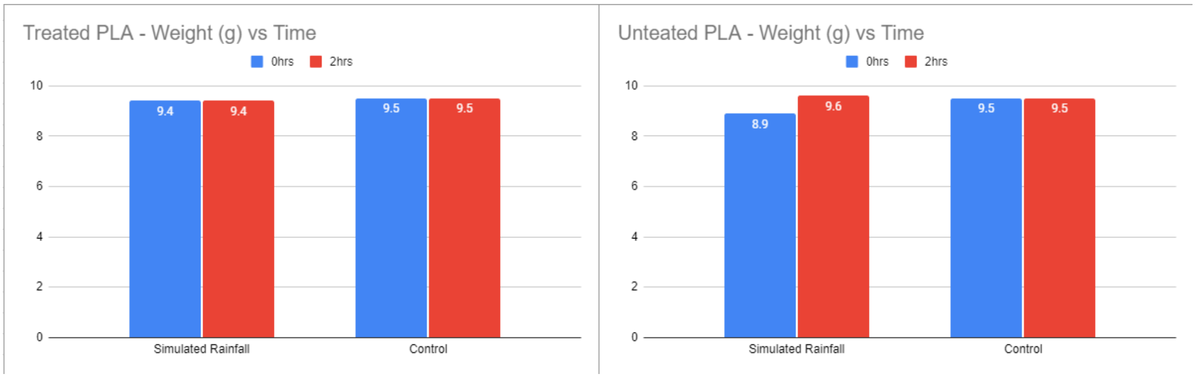

Figure 32: Comparison of Weights after Waterproofing Tests

8.2 System Demonstration

After extensive work on creating a more sophisticated prototype of the robot, the features and capabilities of the system were demonstrated to our project sponsor at Eversource. Additionally, video of a similar demonstration was collected for future use.

8.2.1 State Machine, System Logic, and Deterrents

The state machine was first demonstrated by having the robot patrol the wire uninterrupted. Using the onboard encoders, the robot was able to reverse directions at the end of the wire, or at a different specified location. While the robot was patrolling, the robot was interrupted with a non-raven obstacle to demonstrate the integration of the ToF distance sensors. When the robot encountered a non-raven obstacle, it would stop moving and wait for said obstacle to clear its trajectory before proceeding down the line. Additionally, the robot was interrupted by holding a model raven while it was patrolling to demonstrate both the AI and the onboard deterrents. The lights and sound system were activated until the robot no longer detected a raven in its path, proceeding in its intended direction once safe to do so.

8.2.2 Mobile Application

During the aforementioned demonstration, the web application was run to demonstrate that the robot and web app could communicate and effectively convey the system's information. As the robot moved down the line, the distance from the center as well as the robot's state would be displayed below the visual representation of the transmission line. This visual representation, as seen in Figure 33, is updated in real time to reflect both the robot's position and state by changing the color, icon, and position of the animated "robot" on the static "line".

Figure 33: Real Time Display of System Information

8.2.3 Power Deliver and Battery Management Systems

During the entirety of the live demonstration, the robot received its power from the onboard battery. On a full charge, the robot is able to patrol the wire for a maximum of 1 hour before showing signs of low battery, such as weak drive train movement and dimmer deterrent lights. The voltage reading where this is noticed is below 10.5V.

While testing wireless charging capability with the solar charging setup, the power supply battery was only able to charge up to 13V with the energy from the solar storage battery, since this storage battery is smaller than the power supply one. Wireless charging was not tested with solar panel connected. Overall, the battery takes about 2.5 hours to wirelessly recharge to about 16V with an external power source powering the wireless transmitter.

In addition, all the individual electrical components in the charging system have been individually tested for power draw compatibility.

8.2.4 Video Demonstration

The previous information that is true of the live demonstration is applicable to the video demonstration with the following exceptions:

1. The encoders were limited to not exceed the frame of the video rather the end of the wire.
2. The power was supplied externally, rather from the battery.

The video can be found on YouTube here.

9.0 Future Work

The methods implemented with the new Bird Deterrent Robot prototype further developed existing methods. Testing the robotic system led to discovering areas of improvement unforeseen by the initial design. This robotic system will need to benefit from further refinement before being fully deployable.

9.1 Update System for Cormorant Detection and Deterring

At the close of this project, the team and Eversource representatives discussed future avenues for this robot. The main proposal was to shift away from detecting and deterring ravens at Rimmon Substation to deterring cormorants from live wires in Cape Cod. Should this endeavor be perused, the AI would need to be retrained to detect cormorants. We would recommend purchasing an artificial Cormorant like the one seen in Figure 34 to train the AI as we did with ravens.

Figure 34: FHUILI Cormorant Bird Model (Amazon.com, 4/19/2023)

9.2 Improve User Experience

While the mobile app can send data packaged as a JSON to the web server, the current iteration of the web server does not respond to the information it receives. This results in the buttons on the mobile app that start, stop or control the robot to have no functionality. We recommend future teams parse incoming commands sent on their respective button presses so the state machine can react accordingly. Attaching an onboard mobile hotspot and integrating mobile app-based teleoperation would mitigate the range limitations of the radio controller and its existing tele-op system. The team found that T-Mobile had adequate cell service at Rimmon Substation. Finally, we recommend that an LED strip is attached to the bottom of the robot around the battery compartment to convey state information and robot status visually to operators. This LED strip would blink at different rates as different colors to distinguish the current state of the robot. An example protocol is listed in Figure 35.

State	LED Color	LED Blink Pattern
Idle	Red	Solid
Patrolling	Green	Solid
Charging	Yellow	Solid
Returning to Base	Yellow	Blinking
Tele-op Active	Blue	Blinking
Deterring	Green	Blinking

Figure 35: Example LED Status Protocol

9.3 Further Research into Temperature Concerns

A complication with deploying a robot outside during increased weather arises from concerns over the electrical components overheating and failing. The waterproof enclosure as detailed above impedes cooling of electrical components. It is currently unknown how much the ambient temperature of the enclosure will increase in sustained sunlight while operating. It is advised to conduct tests to determine the heating characteristics of the system in use over the operating period to determine if components heat to unsafe levels.

Initial areas of research could include redesigning mounting structures to include ventilation cut outs. Currently component mounting structures could act as insulators, though it is unknown how insulating they may be.

9.4 Improve Upon Charging Station Solution

Currently the charging station dock is set up to provide charging to the back of the line deployable robot, which is the side of the robot closest to the docking station. The robot drives up to the docking station and presses up against the sealed waterproof container for charging.

However, complications with the battery compartment design required the wireless receiver module to be located on the bottom face of the robot, underneath the line. Due to this complication, a new docking station must be designed in which the wireless transmitter can reach the bottom face of the robot battery compartment to provide charging.

9.5 Carriage Weatherproofing

The Carriage provided by the previous team was an excellent mobile platform for traversing the cable; however, it is currently made of the 3D printed plastic PLA which is expected to be a potential failure point when operating at length outdoors. From the testing mentioned in Section 8.1 Waterproof Testing, water can seep into 3D printed components and degrade the material, weatherproofing measures should be applied to the Carriage. One potential avenue includes treating the surface of the carriage with aerosolized acrylic sealant. This method of sealing 3D printed parts proved in our testing would prevent water from seeping between layers and into the part.

9.6 Electromagnetic Interference Shielding

Electromagnetic Interference (EMI) is caused when an electromagnetic field interferes with the proper functioning of an electronic device. EMI can cause distortion or disruption of electronic signals, which can lead to malfunctions, errors or data loss. EMI may be minimized or eliminated through shielding, filtering and grounding. Although the electromagnetic fields created by a live transmission line are not expected to cause radiated EMI to the robot, proper EMI shielding precautions should be implemented. However, conductive EMI precautions must be installed onto all parts of the robot that makes contact with the transmission line.

10.0 Discussion and Conclusion

The current iteration of the robot provided a weatherproofing solution for the majority of the deterrents, electronics and docking station. The Spire effectively consolidated previously exposed deterring and detecting components. This consolidation greatly reduced the overall form factor of the robot. Furthermore, the new design allowed for the use of iterative testing methods.

Currently, the robot can detect ravens along a transmission line using the AI model by using computer vision and the onboard webcam. Once a raven was detected, the system would deter the raven using visual and audio stimuli located collinearly along the line. The robot drove along the transmission line and relayed information to the mobile app in real time. Finally, the robot was charged wirelessly using the Qi-wireless pad located on the bottom of the battery compartment.

Due to conflicting design and state machine testing timelines, the testing methodologies were not fully addressed. More extensive research is required in the following areas: expanded teleoperation and multiangle AI detection with its respective infrastructure. The addition of the Spire mitigated common hardware concerns and allowed for future improvement of the robot software. The current software was developed such that it can serve as a strong framework for future development. Key framework features included: skeleton code for additional states in the state machine, examples for sending data to the web server for tele-operation, and example code for multi-camera AI detection.

A key takeaway was that technical documentation was critical for the further continuation of the robot. A major challenge encountered was the lack of technical documentation. This lack of documentation inspired great emphasis in this teams detailed documentation methods. These documentation methods included comprehensive steps to troubleshoot common bugs and issues. Please refer to this project’s associated OneDrive and Appendix III: Working with the Bird Deterrent Robot for further resources.

This robot serves as a proof-of-concept prototype that introduces substantial research and testing towards a fully autonomous bird deterring system. Key outcomes from this year's efforts include: detecting and deterring ravens, and reconstructing weatherproof enclosures that facilitate continuous outdoor operations. Future iterations of this robot may add features to the existing system and test the robot on-site.

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Appendix I: Detailed Requirements

The requirements listed in Section 3.0 Project Needs and Requirements are further elaborated below:

Autonomously patrol the power distribution cable for at least 9 hours (8am-5pm).

- Tested by running robot on non-live power line at Rimmon Substation
- Measure number of hours that robot is successful
- Passes if:
  - Physically remains on wire.
  - Able to be on "patrol" mode (moving and searching for birds)
  - Autonomously moves along the length of the wire.
  - Returns to charging port after patrol period.
- Traces to:
  - Need 2 - Deter birds autonomously whilst on a power line.
  - Need 5 - Withstand varying weather conditions that may occur on an outdoor power line in New England

Climb a maximum inclination of 30 degrees without slipping.

- Tested using wire in the WPI lab with maximum inclination of 30 degrees with wet power line conditions.
- Measure distance between the robot and the end of the wire
- Passes if:
  - Distance is 0
- Traces to:
  - Need 1 - Detect birds on and off the power line.
  - Need 2 - Deter birds autonomously whilst on a power line.
  - Need 5 - Withstand varying weather conditions that may occur on an outdoor power line in New England

Detect birds with 85% accuracy within 360 degrees of the robot that are landing on power distribution cables.

- Tested by running AI Bird detection algorithms on the robot while in WPI lab and at Rimmon Substation at 30-degree increments around the robot.
- Measure how many false positives/negatives vs true values
- Passes if:
  - Less than 15% false positive rate
  - Less than 15% false negative rate
  - Detection occurred at every angle.
- Traces to:
  - Need 1 - Detect birds on and off the power line.

Cause a bird to voluntarily leave the 20m x 20m area within 15 seconds.

- Tested on non-live wire at Rimmon Substation
- Measure time it takes to make a bird leave a defined area.
- Passes if:
    - Bird leaves defined area in 15 seconds of deterrent activation.
    - Robot interacted with bird in question.
- Traces to:
    - Need 1 - Detect birds on and off the power line.

Stop before contact with objects on the power cable.

- Tested with robot on non-live wire in the WPI lab using various objects.
- Measure smallest distance between robot and object on wire.
- Passes if:
    - Distance between robot and deterrents is never within 1 foot of bird/object.
- Traces to:
    - Need 3 - Avoid Harming birds or other wildlife.

Implement IP67 rating to withstand varying extreme weather conditions.

- Test by spraying robot housing at all angles with a jet of water from a pressure washer for at least 10 minutes.
- Test by thermally cycling the housing by heating in an oven to X degrees then placing it in a freezer for 15 minutes, followed by same waterproof testing as before for 10 minutes.
- Measure the volume of water in each compartment.
- Passes if:
    - The total volume of water measured is 0 ml.
- Traces to:
    - Need 5 - Withstand varying weather conditions that may occur on an outdoor power line in New England

Be mountable by a single technician in under N minutes without the use of tools.

- Test by if single individual can put on and off the wire.
- Measure the amount of time to mount and the percentage of successful mounting and dismounting.
- Passes if:
    - Repeatably mount and dismount the robot 95% of the time in under N minutes.
- Traces to:
    - Need 6 - Allow reliable and repeatable mounting and dismounting by a single user on the cable.

Override autonomous operation with wireless manual control through radio communication or mobile application.

- Test by controlling the robot via the radio or mobile app and observing the expected response.
- Measure the percentage of successful commands and actions.
- Passes if:
  - 95% success rate for each individual command
  - Never loses contact with the receiver in span of one week.
- Traces to:
  - Need 4 - Allow control by user when needed (tele-operation).

Appendix II: Checklist for Birdbox Deployment

Technical Materials

- ❑ Assembled Birdbox
- ❑ Extension Cord
- ❑ Network Cable
- ❑ Fully Charged Ubuntu Laptop
- ❑ USB Drive for video data
- ❑ Test SIM Cards
- ❑ 360 Camera

Personal Protective Equipment

- ❑ Flame Resistant Clothing
- ❑ Hard Hats
- ❑ Safety Goggles

General Materials and Tools

- ❑ Multimeter
- ❑ Measuring Tape
- ❑ Tape
- ❑ Zip Ties
- ❑ Screwdriver Set
- ❑ Aerosolized Acrylic
- ❑ Ray (fake raven)
- ❑ Wire
- ❑ Soldering Iron

Appendix III: Working with the Bird Deterrent Robot

Introduction

The following technical guide was created to familiarize the necessary individuals about the operation and development of the Bird Deterrent Robot. It contains details on how to operate robot, troubleshoot common problems, and technical details about the system. This technical guide is accurate as of May 3, 2023.

Simplified System Structure

First, let's discuss what's on the robot. We have created a system architecture diagram for you that explains the system hardware architecture. It shows what is connected and controlled by which board or system.

- **Jetson Nano**
    - Sound Board
        - Speakers
    - Webcam
    - Serial Connection to the Arduino
- **Arduino**
    - Lights
    - Encoders
    - Electronic Speed Controllers (ESCs)
        - Motors
    - Time of Flight (ToF) distance sensors
    - Battery Sensor**
    - Radio Receiver**

**These have code but are not included in the current iteration.

Software Setup

Now let's get you set up with all the code, CAD, and other information. We have a few repositories on GitHub. This is all included on the Bot on a Wire (BOAW) organization. To access this, we created a team GitHub account to access on the Jetsons which will be covered a bit later. Reach out to this year's team either on Slack or at gr-birddeterrant-all@wpi.edu to gain access to the GitHub organization.

On this GitHub, you can find the following repositories you will need ...

1. WPIBotOnAWire-ROS
    - This contains all the ROS code, including the AI, the State Machine, and everything that runs on the Jetson Nano.
2. WPIBotOnAWire-Arduino
    - This contains the code for the deterrents, the encoders, the distance sensors, and the motors.
3. BOAW-MobileApp
    - This is made in REACT and provides a way to view the robot information as it runs.

All our CAD models are located on the GrabCAD. Reach out to one of us on Slack and we can add you to the organization.

The Jetsons

Figure 36: Jetson 1 with Plate to hold in SD Card

We have two Jetsons, Jetson 1 and Jetson 2. These are differentiated by a number written on the respective Jetson's Ethernet port. Note that Jetson 2 has a slightly different WiFi card than Jetson 1 and has antennas. Jetson 1 has a broken SD card holder, so there is a 3D Printed brace to hold it in see Figure 36. You can SSH into these Jetsons using **ssh jetson@boaw-jetson1.dyn.wpi.edu** and **ssh jetson@boaw-jetson2.dyn.wpi.edu.**

Re-flashing the Jetson(s)

When the Jetson decides to go to the shadow realm, you will need to reflash its software. We use the following custom image file to run Ubuntu 20.04 and ROS Noetic.
https://github.com/Qengineering/Jetson-Nano-Ubuntu-20-image

Download the image where it says “Download the image JetsonNanoUb20_2.img.xz (7.9 GByte!) from our Sync.” We also have an upload of the image in the team drive, located here. The easiest way to flash the firmware is by using the Rasperry Pi Imager, as it allows for the flashing of a img.xz file to an SD card. You can select the img.xz file you downloaded when using the imager and upload it to the board. If you run an image file not specifically designed for the Jetson, expect problems. ***Do not download an image from the Ubuntu website like you would with your laptop.***

ROS Installation

Once Ubuntu is installed, you will need to install ROS Noetic. You can follow the directions below to install ROS in the Linux terminal in one go...
http://wiki.ros.org/ROS/Installation/TwoLineInstall/

Connecting Jetson to WiFi

Now you need to reconnect the Jetson to WPI WiFi. Follow this guide on the WPI hub. If this link no longer works, ask IT how to connect a Raspberry Pi to the internet.

You will need...

- Monitor
- HDMI Cable
- Ethernet Cable
- Keyboard and Mouse

There is a chance that when we graduate that the Wi-Fi registration will expire and you will need to redo this process again. It is currently registered under jleserman@wpi.edu. If you need to re-register the jetson for the first time and it says that the MAC address is already registered, reach out on slack to remove it or ask IT to remove the following MAC addresses...

Jetson 1 Wireless: **74:d8:3e:45:3d:69**

Jetson 1 Ethernet: **00:04:4b:e7:5f:83**

Jetson 2 Wireless: **28:d0:ea:89:fa:03**

Jetson 2 Ethernet: **48:b0:2d:5c:25:50**

Connecting GitHub/SSH Keys

To connect your GitHub account to the Jetson, follow the guide below to connect an account with the SSH agent. From there you can pull the proper repos from the BOAW organization. https://docs.github.com/en/authentication/connecting-to-github-with-ssh/generating-a-new-ssh-key-and-adding-it-to-the-ssh-agent

Launch the code

Assuming everything is set up on the Jetson, run the following commands to launch the Arduino, state machine and bird detection.

1. ssh into the jetson in 4 windows
2. cd catkin_ws/src/WPIBotOnAWire-ROS in all windows
3. roslaunch robot.launch
4. python3.8 boaw_sm.py
5. python3.8 detection_raven_ros.py

Appendix IV: Wiring Diagrams

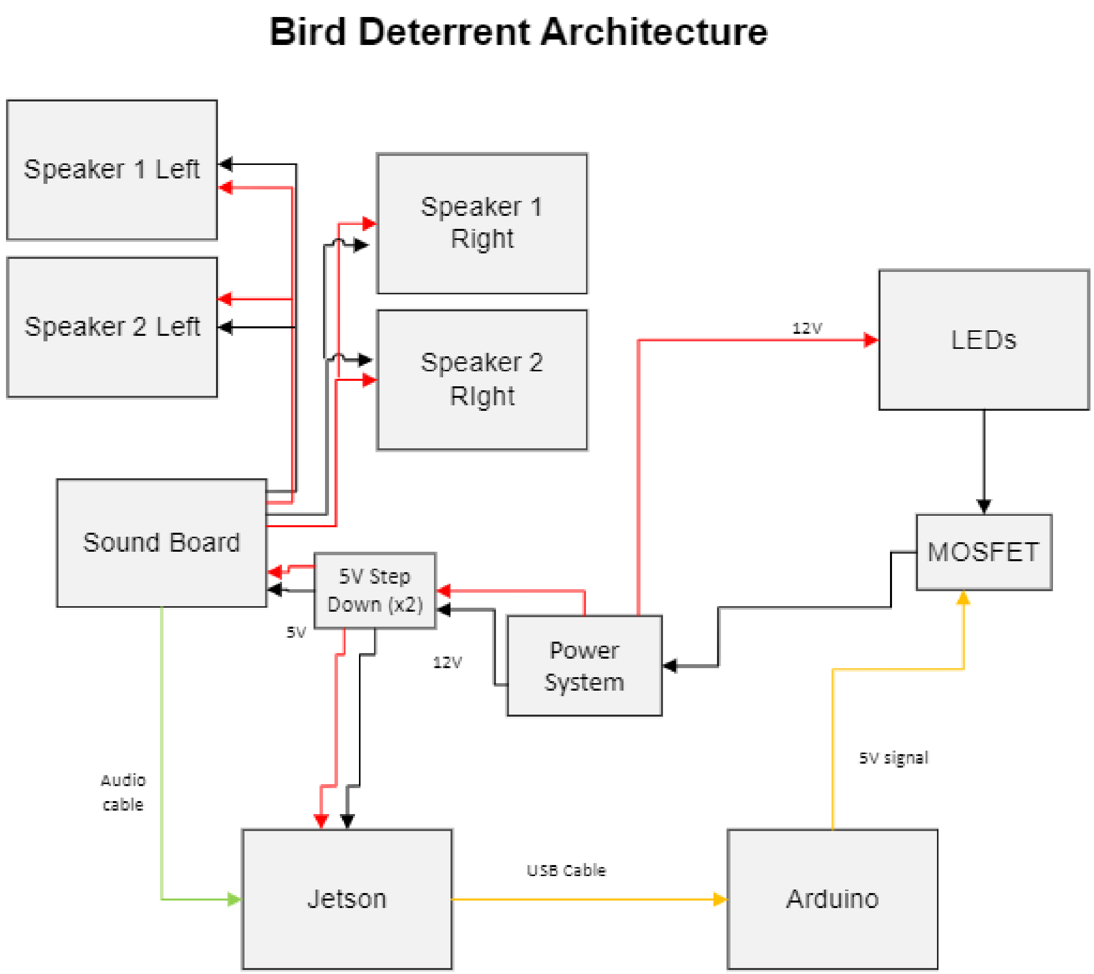

Figure 37: Bird Deterrent Wiring Architecture

Power System Architecture

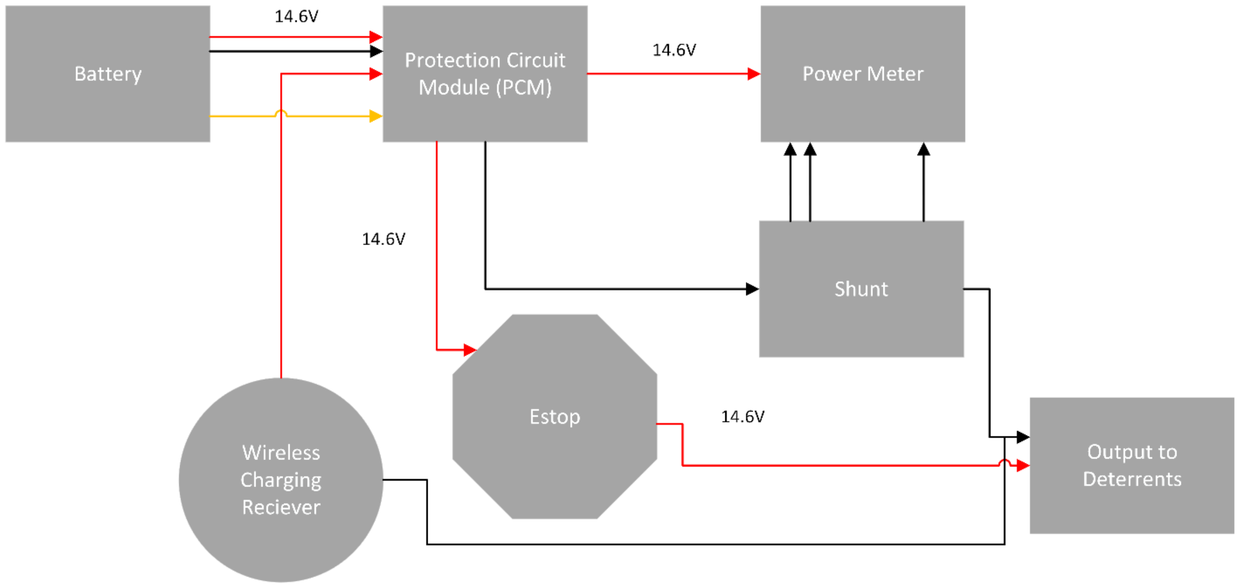

Figure 38: Power System Architecture Diagram