Electrical and Computer Engineering
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Senior Capstone Final Project Report

JumpGuard: Making the Terrain Park Safer One Jump at a Time

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JumpGuard

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Executive Summary

Project Title: JumpGuard

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Customers:
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Problem Statement:

Many ski resorts today have terrain parks, which are collections of jumps and obstacles that can be ridden by athletes. Depending on the size of terrain park jumps, athletes can't always see the landing area before committing to the jump. So, if an athlete crashes on the bottom of a larger jump, athletes uphill may not be aware of the risk of collision awaiting them at the bottom of the jump.

A system was designed to detect when the landing area is clear before notifying the next athlete that it is safe to proceed from the top of the hill. The system operates in inclement weather throughout the winter season. The system operates on a stand-alone power system to avoid running power lines to the system, which could create unnecessary hazards.

Project Overview:

To address this safety hazard, the JumpGuard system was designed. JumpGuard is a modular, wireless, solar-powered visual signaling system designed to alert skiers and snowboarders at the top of a jump whether the landing zone is clear. The conceptual block diagram in Figure 1 can be used to visualize this project. It consists of two physically separate components:

1. **Downhill Detection Unit** – Positioned near the landing zone to monitor for the presence of athletes.
2. **Uphill Signaling Unit** – Located at the top of the jump, this unit displays either a red or green light to indicate if the landing zone is safe to proceed.

These components are linked via a long-range LoRa communication system and powered independently using solar panels and battery systems. A manual override switch allows resort personnel to force the system into a red-light "stop" state in emergencies.

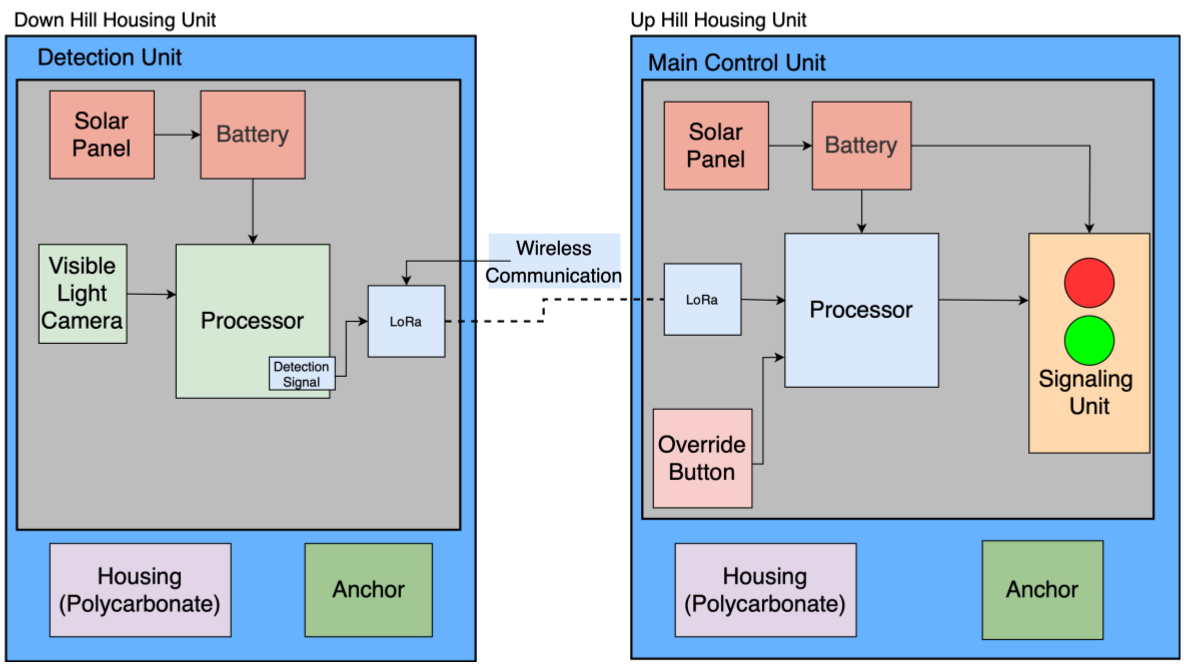

Figure 1: Conceptual Block Diagram

Subsystem Summary and Results:

- **Detection Subsystem:**
  The detection unit uses a visible light camera connected to a Raspberry Pi, processing images via an image subtraction algorithm to detect changes in the detection area. While initial testing showed promise under controlled conditions, the detection subsystem struggled to perform reliably in real-world settings and was excluded from final deployment. This remains a critical area for future work and refinement.

- **Communication Subsystem:**
  LoRa communication between the units is highly reliable, with measured latency well under the 0.5s requirement. Low dropout rates and robust transmission were achieved over a 60 ft line-of-sight range, validating the subsystem's design. The MSP430 microcontroller successfully interpreted LoRa messages and toggled the lights with rapid response times.

- **Signaling Subsystem:**
  The uphill signaling unit employs bright PAR36 LEDs with a red and green color filter to indicate whether it was safe to proceed. Both lights exceed the 1000-lumen visibility requirement, verified under multiple lighting conditions.

- **Power Subsystem:**
  Each unit operated independently on its own solar charging system with a LiFePO4 battery and MPPT charge controller. The system reliably operates for more than seven hours, with sufficient recharge capabilities achieved in typical winter daylight conditions. This design eliminated the need for hazardous cabling in snow-covered environments.

- **Housing and Mounting Subsystems:**
  Custom-designed polycarbonate housings and adjustable aluminum mounting brackets protected all electronics from snow, wind, and temperature extremes. The housings were shown to withstand environmental testing, ensuring the electronic components remain functional. The adjustable mount design permits all units to be easily installed and repositioned as snow levels change.

Conclusions and Recommendations:
JumpGuard successfully demonstrates a deployable wireless signaling system for ski terrain parks, achieving reliable performance in communication, power management, visibility, and weather resistance. Although the detection subsystem did not meet expectations and requires further development, the modular design of JumpGuard enables easy replacement or upgrading of components.

The system is field-deployable, durable, and represents a solid foundation for improving safety in terrain parks. Future improvements should focus on refining or replacing the detection subsystem—potentially exploring region filtering with thermal imaging. [1]

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1. Introduction

1.1 *Project Motivation*

Many ski resorts today have terrain parks, which are collections of jumps and obstacles that can be ridden by athletes. Depending on the size of terrain park jumps, athletes can't always see the detection area before committing to the jump. So, if an athlete is present at the bottom of a larger jump, athletes uphill may not be aware of the risk of collision awaiting them at the bottom. This could lead to serious injury and potential trips to the hospital for the athletes involved in an incident. It has been reported that features in a terrain park that promote aerial maneuvers account for 83% of total terrain park injuries [2]. Due to the popularity of terrain parks in ski resorts, the risk and occurrence of injury to athletes will persist unless preventative actions are taken.

1.2 *Project Description*

Because of the obstructed view created by the large jumps in a terrain park, it is crucial to provide a way for athletes uphill to know whether the detection area is clear to prevent potential collisions and injury. Therefore, a system has been designed to detect when the detection area is clear before notifying the next athlete that it is safe to proceed from the top of the hill, JumpGuard. It determines whether the detection area below a jump is clear and then reports the status to athletes uphill from the detection area. JumpGuard operates in inclement weather throughout the ski season and operates on a stand-alone power source to avoid running power lines to it, which would create unnecessary hazards. The JumpGuard system consists of two separate units, a lower detection unit for detecting athletes, and an uphill signaling unit that displays the status of the detection area to uphill athletes.

The function of the lower unit is to detect athletes in the detection area of a jump. When an athlete is detected in the detection area, the lower unit will transmit this information to the signaling unit. Because of the inherent risk of safety, wires between units were not used. Alternatively, the detection unit operates on a standalone power source and transmits data to the signaling unit wirelessly.

The signaling unit's primary purpose is to display either a green or red light, indicating whether the detection area is clear of athletes or not. The signal displays the state of the detection area by processing the wireless information received from the detection unit and then changing the light color based on the status of the detection area. Like the detection unit, to prevent safety concerns, the signaling unit operates on a standalone power system. This power system is not the same as the power system used by the detection unit.

1.3 Project Background

In the background section there are three subsections, the initial state of the project, the technology review, and the applicable standards. The first section, the initial state of the project section is meant to explain the initial information that is known about the project before the design was began. The second section, the technology review, dives into a literature review of the important technologies that are used in the design of the JumpGuard system. Finally, the applicable standards section provides the in information of any known engineering or public standards that are used or connected to this project.

1.3.1 Initial State of the Project

The first terrain park was opened in Bear Valley Ski Area (California) during the 1989/90 season [3]. Since the creation of the first terrain park, they have generated a lot of popularity amongst ski resort athletes all over the world. With the surge in popularity, the features have now advanced into larger scale versions of previous iterations. One of the most common and popular features that can be found in a terrain park are jumps. Terrain Park jumps are designed to utilize athletes' downhill momentum to propel them into the air over a ranging distance called a "gap". After clearing the gap, athletes will land in the detection area and proceed to the bottom of the run.

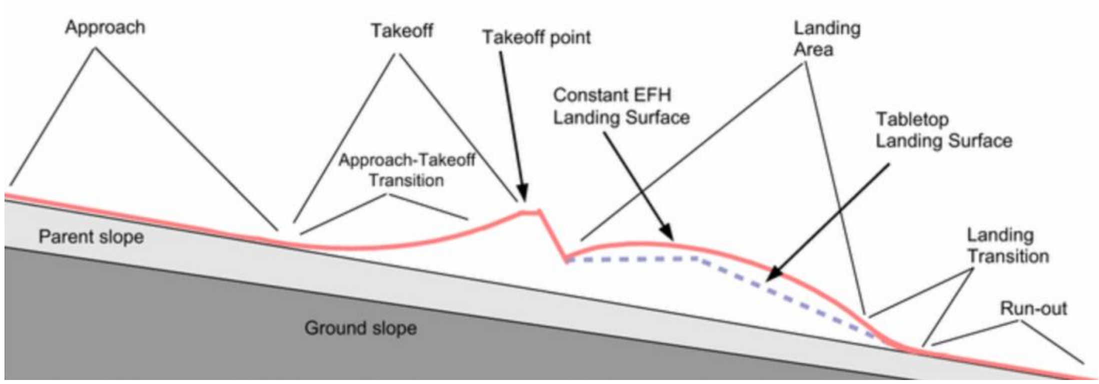


Figure 2: Terrain Park Jump Diagram [4]

A typical terrain park jumps, consists of several important features. The approach and takeoff sections are where the athlete builds speed before launching into the air at the takeoff point. This is followed by the constant equivalent fall height landing surface, which is a measure to ensure that the slope of the landing zone reduces the impact of landings. Athletes attempt to land their jumps on this flat landing surface but often overshoot or undershoot the detection area. Due to the height of the takeoff point, the landing zone is not always within a clear line of sight for an athlete coming down from the approach.

Around the jump, visibility is crucial for riders to assess whether the detection area is clear or occupied. There have been multiple instances where the "blind spot" on terrain park jumps have led to serious collisions. One notable case occurred at Mammoth Mountain, where a snowboarder landed directly on a girl who was in the blind landing zone of a jump. The snowboarder had no idea someone was in the detection area, which is a common risk when the jump obscures the view of the detection area. This incident, captured on video, highlighted the danger of not being able to see the landing surface before taking off. [5]

Ski resorts have long recognized the inherent risks involved in terrain parks, especially since they cater to athletes of varying skill levels. Traditionally, safety in terrain parks has been maintained through basic traffic flow measures such as signage and resort personnel acting as spotters [4]. These methods, while helpful, have several shortcomings, particularly in high-traffic or low-visibility conditions, such as fog or snowstorms. For example, signage can be obscured, and human spotters cannot be present in every key location. These methods can lead to miscommunication and are less effective at-risk reduction. Furthermore, these methods only address the risks after they become apparent, which leaves room for dangerous situations to arise.

1.3.2 Technology Review

This technology review explores past systems, projects, and technologies that are relevant to developing a stoplight system for terrain park jumps. This report aims to provide a comprehensive understanding of how modern advancements in safety technology, communication, and sensors can be integrated into a terrain park stoplight system to improve athlete safety.

<u>SmartPatrol System:</u>

Many ski resorts implement various safety measures to reduce the risk of accidents in terrain parks. Some examples of these safety measures are the Park Smart program, special signage, or employing human spotters. There are very few systems designed to detect the presence of others in landing zones. Research led to the discovery of only one system that accomplishes this, known as SmartPatrol [6]. The SmartPatrol system, Figure 3, is similar to the designed system, detecting the real-time status of the detection area of jumps and relaying that information to those uphill. This system achieves its task by using a camera fed into computer vision algorithms to determine if the area is clear [7]. While highly innovative, being the first of its kind in the field allowed room for improved development.

Figure 3: SmartPatrol System in Use [7]

Unlike the SmartPatrol system, the JumpGuard system uses solar energy as its primary power source, instead of batteries. This reduces the need for battery recharging and aligns with the net-zero goals of many ski resorts [7]. JumpGuard utilizes a detection unit that is separate from the signaling unit. The separation of the two units provides a method that is more versatile between different sizes and designs of terrain park jumps.

<u>Communication:</u>

There are a variety of ways wireless communication can be achieved across a terrain park. Factors such as interference, range limits, and environmental factors like weather are all things that were considered. Below is an alternatives analysis of a few different wireless communications methods.

Figure 4 below shows the alternative analysis of different wireless communications methods. The characteristics used were cost, range, data transfer rate, reliability, startup time, and power consumption.

Characteristics	Weight	Wifi	Bluetooth	LoRa
Cost	4	3	3	2
Range	4	1	3	5
Data Transfer Rate	1	4	3	1
Reliability	5	2	3	5
Startup Time	3	2	3	5
Power Consumption	5	2	4	5
Final		46	71	94

Figure 4: Wireless Communication Alternative Analysis

WIFI is one possible method of wireless communication. As one of the fastest and most used methods of data transmission, it has potential within the system due to the available components and documentation online. Using WIFI in an outdoor setting with obstacles, such as in a terrain park, would lead to a range of roughly 50-100 feet, which is on the cusp of what was needed [8]. Additionally, WIFI has a very high data transfer rate, which could be overkill and lead to unnecessary power consumption.

Bluetooth is also a popular method of data transmission, mostly used in headphone and sound applications. Standard Bluetooth modules, commonly found in most Bluetooth devices, are of class 2, which usually has a range of roughly 33 ft [9]. Class 1 Bluetooth modules, used in industrial applications, have the ability to reach up to 300 ft, though a significant increase in power is required [9]. Due to this higher power consumption and the system having a stand-alone power source, class 1 Bluetooth modules were not a compelling option. Class 2 Bluetooth modules may be a viable option, if there is a way to increase range.

LoRa is a form of communication that utilizes a wireless modulation technique known as chirp modulations. In this method, the frequency of a LoRa chirp radio wave increases or decreases with time. By altering different characteristics of the chirp wave, data can be transmitted effectively [1]. This technique allows for the radio waves to communicate over 5 miles in an open outdoor setting [10]. LoRa is also known for having ultra-low power consumptions, which fit the system with the limited power supply. A downside to LoRa is the data transfer rate, which was overlooked due to the low amount of data needed to be transmitted.

Sensors:

The sensors for the project were a critical component of the system. Without the sensors to detect the athletes at the bottom of the hill, there is no way to transmit to the top of the hill that the jump is clear. Several technologies were researched in order to decide what sensor would be best suited for this project. The characteristics of a good sensor were, low cost, reliability, sensitivity that suits the system, good resolution, ability to withstand cold temperatures, and a far enough range to detect a 30-foot by 30-foot square. Many sensors, like passive IR sensors are used all around the world today. [11] The sensor that was found to be the most beneficial to the project was a thermal camera and visible light camera duo.

Thermal sensors measure physical parameters based on the heat or flux change. These sensors have a high sensitivity to change in temperature. Depending on the resolution of the sensor the price can range from $75-$8,000. This sensor is typically more accurate in registering different temperatures reliably than other sensors. The ability of this sensor to act at lower temperatures is greater than most other sensor's due to its ability to read temperature. It can detect differences in temperature up to 0.02ºC. Depending on the price and resolution of the sensor this value could be greater or worse. The reliability of the thermal sensor can depend on various inputs. For example, the temperature drift, ambient temperature, and the distance that is being measured. The range of this sensor is from a few centimeters to several hundred meters.

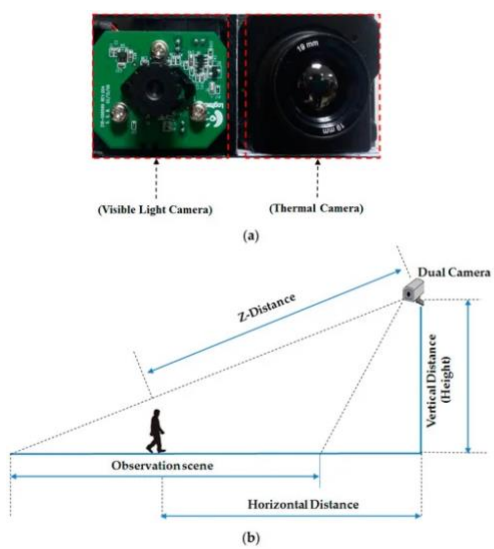


Figure 5: Imaging Setup to Detect People Using Light Camera and Thermal Camera [12]

Additionally, visible light cameras range from $20-$2000. Visible light cameras would be able to recognize differences in the environment that do not provide an increase in temperature. Visible light cameras, depending on price and brand, can withstand temperatures as low as -40ºF. These cameras provide more data to the program than the thermal camera as it is able to see more things in the detection area.

A dual camera system could have been used to track distance and positioning of an "observation scene", as seen in Figure 5. However, there was no need for such a robust system and the visible light camera provided enough information from the system to move forward with it alone. This saved money on cost, and the extra processing time that would be needed to interpret two images. However, the placement of the thermal camera was left in case it needed to be added in the future by the sponsors.

<u>Image Subtraction:</u>

Image subtraction is a technique used predominantly in motion detection, background subtraction, and object tracking. [13] It is done by subtracting two images from each other and analyzing the differences between the two images. It can be used in comparing different frames of a set of images taken at different points in time. This can detect images from frame to frame.

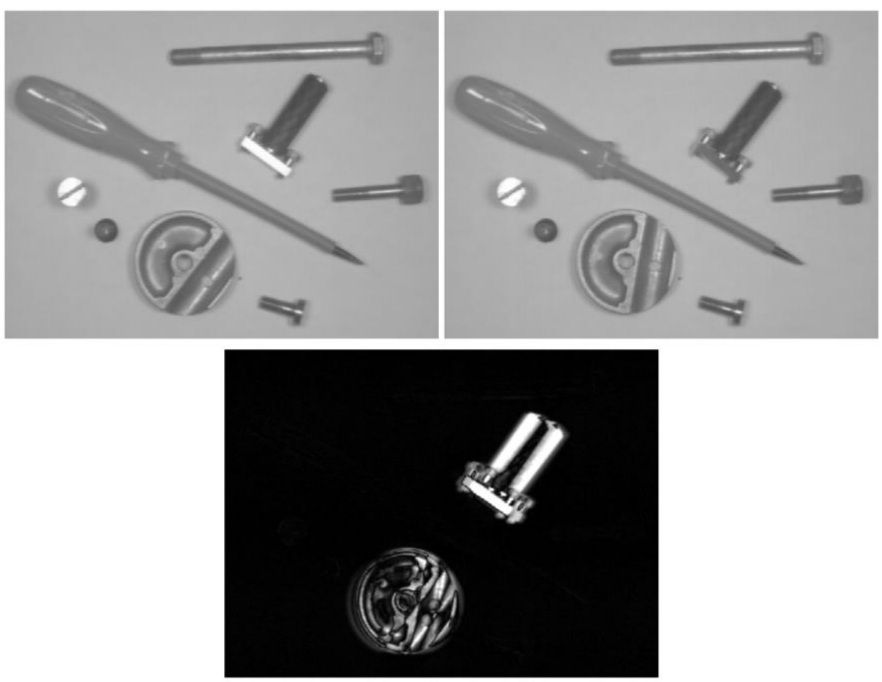


Figure 6: Image Subtraction Example [14]

In order to process the images in real time and determine whether an athlete is present in the detection area, image subtraction is used. In order to use image subtraction to determine if an athlete is in the detection area, a previous image will be compared to a current image and then subtracted from each other. If the absolute value of the difference is greater than a threshold then the system has indicated that there is an obstruction in the detection area.

Some preprocessing must be done before the images can be subtracted in order to ensure only the “bigger” changes are being analyzed in the image. These include greyscale conversion and binary image conversion. Both of these preprocessing techniques minimize the “noise” in the background of the images and allow the focus of the subtraction to be the object. Small changes at a pixel level can become prominent in environments with wind or shifting of the sun. These small changes in the image can sometimes increase to be a larger change overtime that effects the value of the threshold. In addition, the conversions create an image with less pixels to analyze and by doing so causes faster processing times.

Image subtraction is a very effective way to determine differences in images. It is used in object tracking, motion detection, and background subtraction. It is an efficient way to process difference images in a short period of time. For the simplicity of this project this is a proficient way to determine the presence of athletes and obstructions in the detection area.

1.3.3 Applicable Standards

With the development of a new product, it is important to take into consideration regulations and standards that relate to the project. Some areas related to the project are prohibited radio frequencies, power regulations, Montana traffic light laws, and communication standards. These standards ensure that the system will be able to operate safely and successfully.

With the use of wireless data transmission between the signaling unit and detection unit, a potential solution could be that of radio communication. Radio transmission is not prohibited, although there are multiple prohibited frequency bands [15]. These prohibited frequencies, Table 1, are important to consider if radio transmission is used.

Table 1: Prohibited Frequencies [16]

MHz	MHz	MHz	GHz
0.090-0.110	16.42-16.423	399.9-410	4.5-5.15
[1] 0.495-0.505	16.69475-16.69525	608-614	5.35-5.46
2.1735-2.1905	16.80425-16.80475	960-1240	7.25-7.75
4.125-4.128	25.5-25.67	1300-1427	8.025-8.5
4.17725-4.17775	37.5-38.25	1435-1626.5	9.0-9.2
4.20725-4.20775	73-74.6	1645.5-1646.5	9.3-9.5
6.215-6.218	74.8-75.2	1660-1710	10.6-12.7
6.26775-6.26825	108-121.94	1718.8-1722.2	13.25-13.4
6.31175-6.31225	123-138	2200-2300	14.47-14.5
8.291-8.294	149.9-150.05	2310-2390	15.35-16.2
8.362-8.366	156.52475-156.52525	2483.5-2500	17.7-21.4
8.37625-8.38675	156.7-156.9	2690-2900	22.01-23.12
8.41425-8.41475	162.0125-167.17	3260-3267	23.6-24.0
12.29-12.293	167.72-173.2	3332-3339	31.2-31.8
12.51975-12.52025	240-285	3345.8-3358	36.43-36.5
12.57675-12.57725	322-335.4	3600-4400	([2])
13.36-13.41			

If other wireless communication methods are used, there are other applicable standards, including but not limited to IEEE 802.11, IEEE 802.15.1, and IEEE 802.15.4. These are the IEEE standards for local wireless transmission, Bluetooth, and LoRa.

A solution for the signaling unit could involve the use of a traffic light feature to indicate when the detection area is clear. To ensure the signaling unit is easily understood by athletes uphill, the displayed colors must follow Montana Code 61-8-207 using green to signal go, and red to signal stop [17].

When designing a power system which includes solar panels and batteries, the standards must be obeyed in order to allow for safe day-to-day operations. Standards applicable could be IEEE 1562-2007, IEEE 307-1969, and IEEE 519. These are the IEEE Standards for battery sizing in a PV(Photovoltaic) system, adding solar cells to a power system, and for loads in electrical systems.

2. Project Requirements

This project achieved three major objectives. The first objective was to design a system that would determine whether the detection area below a jump was clear and then report the status to the uphill signaling system. This provided the athlete uphill with knowledge of the detection area status to reduce the risk of collision. The second objective was to design a system that would operate successfully in inclement weather from December through April. This period is peak skiing season, which is when the system will be most used. The system is durable and weatherproof, allowing for use in cold, snowy conditions. The third objective was to design a system that operates on a standalone power system. Being on a ski resort mountain, access to traditional powering methods was limited. This induced the need for a standalone system that is self-sufficient and has reliable energy storage.

2.1 Product Requirements Outline

To achieve these objectives, the following requirements were selected, and the system was built around them:

Table 2: Project Requirements

Obj 1) This system will determine whether the detection area below a jump is clear, and then report the status to athletes uphill from the **detection** area

Req 1.1) System must detect when the detection area is clear

Spec 1.1.1) Detection system must be able to detect athletes within a 30x30 ft area within the detection area

Spec 1.1.2) Must have ≥ 95% detection rate

**Detection is defined as an object being in the frame for more than 2 seconds*

Req 1.2) System must communicate detection results to uphill athletes.

Spec 1.2.1) Latency from when the sensor triggers, to when the signaling unit triggers, must be ≤ 0.5s

Spec 1.2.2) Dropout rate of information must be ≤ 2%

Spec 1.2.3) Sensors must communicate with signaling unit from a maximum distance of 60 ft away with a direct line of sight

Req 1.3) System must notify the next athlete it is safe to proceed

Spec 1.3.1) Signal must produce a green light when the detection area is clear

Spec 1.3.2) Signal must produce a red light when the detection area is not clear

Spec 1.3.3) The latency of the light changing states after a signal is received must be ≤ 0.5 seconds

Spec 1.3.4) Must have a manual override to send the system to the "stop" state in case of emergencies or other events

Obj 2) The system must operate in inclement weather throughout the months of December through April

Req 2.1) Must have housing material capable of protecting electronics while ensuring operation in varying weather conditions

Spec 2.1.1) Must be able to withstand and function in temperatures ≥ 0°F

Spec 2.1.2) Must be able to operate in winds up to 20 mph

Req 2.2) Signaling Unit must be visible to athletes in varying weather conditions

Spec 2.2.1) Must be able to see signaling unit from 30 ft away uphill

Spec 2.2.2) Lights on the signaling unit must produce at least 1000 Lumens

Spec 2.2.3) Adjustable between 0 - 5 feet with height increments by ± 6" for every adjustment

Obj 3) The system will operate on a standalone power system to avoid running power lines to the system which could create unnecessary hazards

Req 3.1) Power source must be reliable in varying winter conditions

Spec 3.1.1) Must operate continuously for 7 hours*

Spec 3.1.2) Must have sufficient backup power to operate normally for 7 operational hours*

Req 3.2) The system must have the ability to recharge both primary and secondary power sources.

Spec 3.2.1) Can recharge for a 7-hour operational day with 3.5 hours of peak sunlight*

Spec 3.2.2) Backup power can be recharged through an external source in 8 hours for the system to operate for 7 operational hours*

***Edited with approval from sponsors and advisor**

2.2 Design Constraints

While achieving these requirements, there were four primary constraints to the design process:

- The system must use solar power as the primary power source.

- The system must provide a light signaling unit to give athletes indication on whether it is safe to proceed or not.
- The system must communicate across units with wireless transmission, to ensure there are no hazards added to the terrain park.
- The system must have manual height adjustment to account for changes in the snow base and to save power.
- System is not meant to operate in visibility lower than 30 ft or when the terrain park is not operational

2.3 Additional Project Requirements or Deliverables

Along with meeting the above requirements, the following deliverables were produced:

- Detailed user manual / instruction set
- All circuit schematics, structural drawings, and PCB artwork
- A verification test plan
- Code diagrams
- Bill of materials

2.4 Team Member and Project Responsibilities

To accomplish the goals and requirements of this project, the responsibilities of certain systems were split up between group members, Table 3. While being in open communication with each other about the project, each member was assigned a focus by area of expertise.

Table 3: Percent Responsibility for Each Team Member on the Project

Name	Detection	Power	Data Processing *	Mechanical Structures	Documentation	Team Management
Riley Holmes	0%	5%	100%	0%	20%	18%
John Podgorney	5%	5%	0%	45%	20%	18%
Ben Caba	10%	60%	0%	10%	20%	18%
Emily Schwartz	60%	15%	0%	0%	20%	28%

Trevor Jordan	5%	5%	0%	45%	20%	18%
Total	100%	100%	100%	100%	100%	100%

**Data Processing being defined as the wireless communication between the uphill and downhill units, and the changing of the Signal Light.*

The responsibilities of each member are explained below:

Holmes:

Riley Holmes' main responsibilities were data processing, documentation, and team management. With data processing being defined as the wireless communication between the uphill and downhill units and the changing of the signal lights, Holmes mainly worked with the MSP430 and Raspberry Pi to implement the wireless transmission functionality. He also designed the printed circuit board for the uphill unit, collaborating to ensure it fit in the housing and connection to the power unit and lights. Along with everyone else in the group, he played a role in documentation and overall team management.

Caba:

Ben Caba's responsibilities in the project were split between the power system, detection, documentation, team management, and mechanical structures. The primary focus of his contributions was on the design and implementation of the system's power in both uphill and downhill units. Power was essential for the operation of all components within the system. It was critical for him to understand the power required by all subsystems, such as the detection unit, signaling unit, microcontrollers, converters, and all other electrical components. All research and design were documented and shared with the group and advisor multiple times a week, allowing for seamless integration between other subsystems in the project.

Jordan:

Trevor Jordan's responsibilities to the project were the mechanical structures of the uphill lighting system. This included the development of an anchoring system and mounting capable of withstanding varying surface conditions. There was a focus on ensuring that the system was durable, easy to install and maintain, and performed consistently in harsh environments. His duties also included full documentation of findings and progress, team management, and integrating his designs with the solar, communication, and power subsystems.

Schwartz:

Emily Schwartz was responsible for the detection unit, documentation, team management, and part of the power system design. This meant implementing the code to read the images in from the camera and interpret them to determine if there was an athlete present in the detection area. This code used image subtraction to maintain an easy-to-follow procedure for detecting athletes. All of the code, theoretical, and functional, was documented and maintained in order to provide to the sponsors. Additionally, the team management added another level of organization, including scheduling appointments and verifying proper schedule alignment.

Podgorney:

John Podgorney was primarily responsible for the mechanical structure of the system, with a focus on the materials used to create downhill system and housings. Additionally, he was responsible for working with the other members to ensure the fit of all components within the downhill housings. His duties included designing the structure of the system, determining the best material to use, determining the best method to build the system, making sure the components were climate resistant, and documenting all findings and progress.

3. Subsystem Design and Verification

The JumpGuard design has two main housing units, the downhill unit and the uphill unit, Figure 7. Each unit is powered by its own standalone power subsystem, which includes a solar panel and battery. Each unit's battery has its own housing separate of the detection and signaling unit. The main purpose of the downhill unit is to house the detection subsystem, which includes a visible light camera and a processor to determine the state of the detection area. The detection subsystem is seen in the green boxes. Once the detection subsystem determines the state of the detection area, it sends that information to the communication subsystem, the blue boxes. The main purpose of the communication subsystem is to wirelessly transmit the detection signal to the uphill unit. In the uphill unit, the communication subsystem receives the detection signal, then processes that signal to control the signaling unit, as seen in orange. The uphill processor also reads the override button's state in case of emergencies.

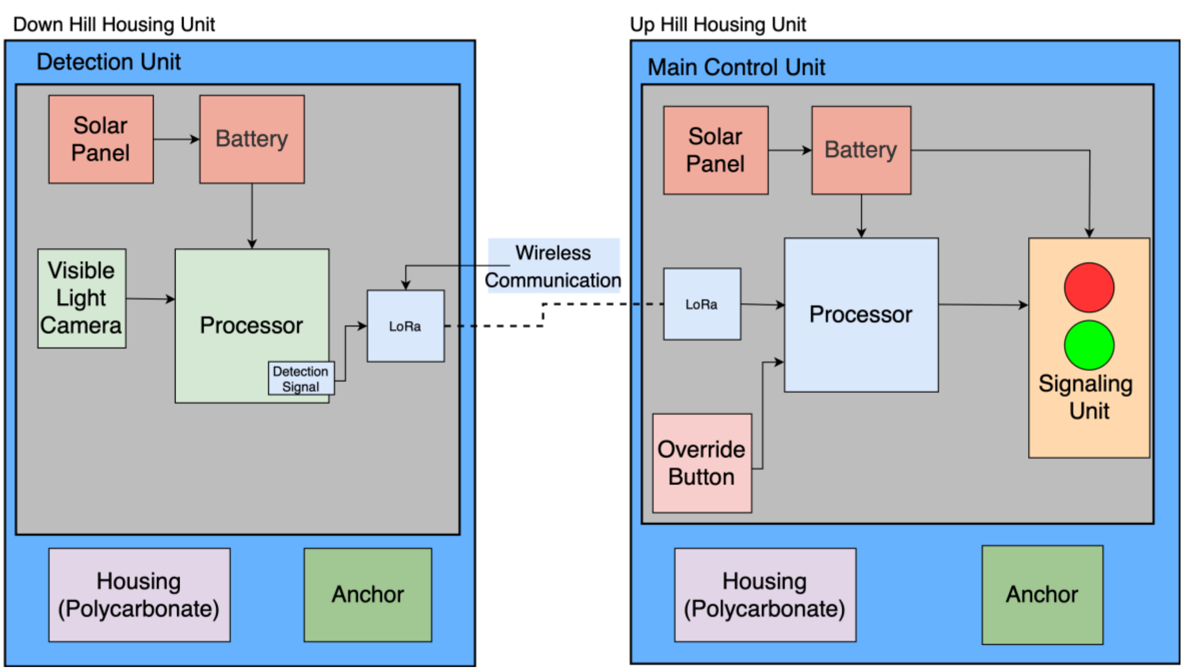


Figure 7: Conceptual Block Diagram

3.1 *Subsystem 1: Detection [Emily Schwartz]*

The detection subsystem includes the visible light camera and the Raspberry Pi processor, Figure 8. The purpose of this subsystem is to detect the presence of an athlete in the detection area at the bottom of a ski jump. This subsystem uses image subtraction to determine the change in the detection area. This processing was done on the Raspberry Pi, using the visible light camera to take the images.

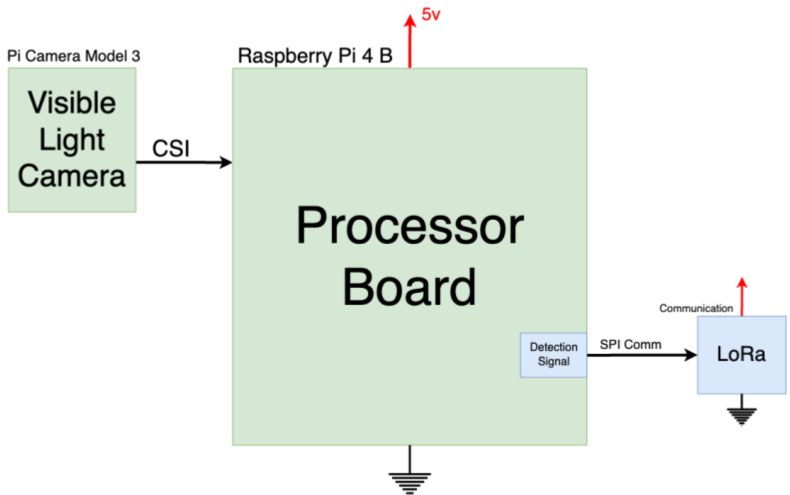


Figure 8: Detection Subsystem Components

3.1.1 *Detection Design*

As mentioned previously, the detection unit is made up of two components: the visible light camera and the Raspberry Pi (Pi). The Raspberry Pi is a small single-board computer that was used to process all of the images using a C program. For the purposes of this project, and in order for ease of use, the Raspberry Pi Camera Model 3 was used. These two components communicate over a 15-pin ribbon cable, labeled CSI (Camera Serial Interface). This also provided an easy interface, to limit the number of mistakes and complexity that could be added to the project.

The main functionality of the detection code, Figure 9, is where all the setup for the processing is done, along with the sending of the detection value. This code is initialized on power up of the downhill unit. The detection and communication code will run continuously until the system is powered off. This process begins with a startup sequence to calibrate the threshold value, Figure 10. This will be talked about in more detail later in the document. The capturing of the image starts the continuous sequence.

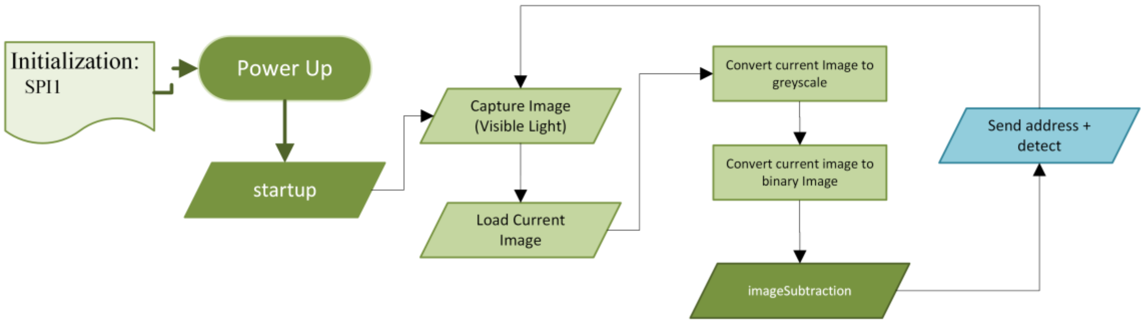


Figure 9: Main Functionality of Detection Subsystem

Once the image is captured and loaded into the code as an array of integers, it is converted into a greyscale image. Converting this image reduces the amount of processing that needs to be done on the image. Instead of computing the image subtraction of two 3-D arrays, the greyscale image minimizes it down to a 1-D array. After the size of the array is reduced, the image is converted into a binary image. This sets all values within the array to either a "1", or a "0". The values are set based on a threshold value dictated by the programmer. If a specific pixel is greater than the threshold, then the pixel is set to the value of "1". If the pixel value is less than the threshold then the pixel value is set as "0". Converting to a binary image minimizes the amount of noise that is read by the camera. This noise could be shifts in trees due to the wind, a cloud faintly seen in the sky, or a shadow shifting on the ground from an object out of frame. The conversion to a simple binary image allows the differences in the image to be more present in the frame because the smaller differences are processed out.

The startup subroutine is meant to provide an accurate threshold value for the system that will allow for varying conditions, Figure 10. This function begins by capturing an image. Once the first image is captured a signal is sent to the uphill unit to turn the light red. This signal allows for the processing to be done before the athletes are notified that the system is ready. The next image is then captured and this begins the loop that repeats 10 times. This loop gathers the difference values of 10 consecutive images. Once the 10th image is taken and the difference is found, the loop is exited.

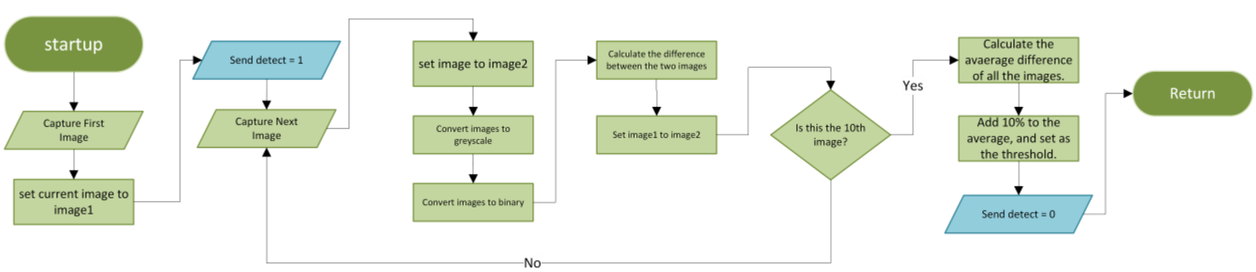


Figure 10: startup Subroutine Flowchart

Once the loop of image captures is exited then the average of all the differences is calculated. This entire time the area needs to be clear so that the system is able to account for subtle differences between each frame. The average differences of the images give a baseline of where the threshold should be. Once the average is calculated 10% is added to the number and that is what the threshold is set to. This allows for a little bit more variation in the differences between images. Then adding 10% will mean that if there is a greater than 10% difference there is an object in the view of the camera. Once this is completed a signal is sent to the uphill unit meant to communicate to the athletes that the system is now ready. This signal will produce a green light.

After the image is converted down to the correct type, in the main functionality, Figure 9, it is sent into the "imageSubtraction" subroutine where that image and the reference image are subtracted to compare the differences, Figure 11. After the difference is determined and the "detect" variable is set, the value and address is sent to the uphill unit. This topic will be discussed in more detail in the 3.3 Subsystem 3: Communication Subsystem.

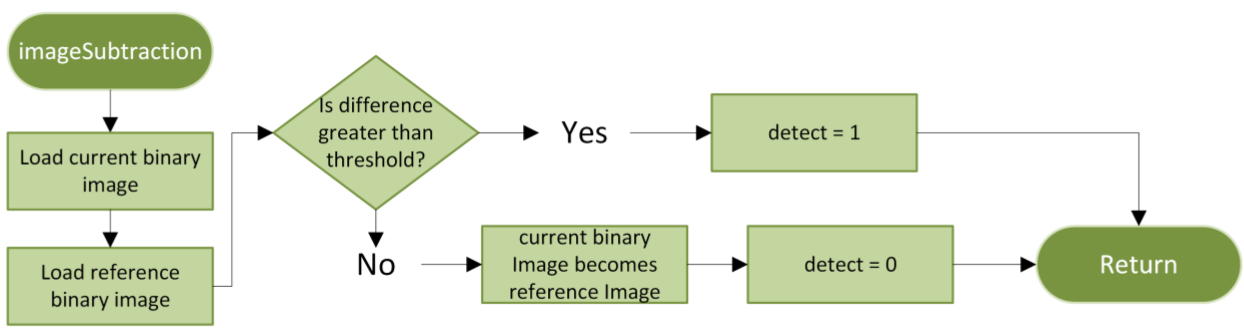


Figure 11: imageSubtraction Subroutine Flowchart

The imageSubtraction subroutine is where the image processing is performed, and the detection of an athlete is confirmed. This process is begun by loading in the two binary images that will be subtracted from one another. This includes the current binary image that was just taken and converted in the main functionality, Figure 9. The reference image is set when the difference of the two images is less than the threshold. When the system is first turned on, the first image taken will be set as the reference image.

The absolute value of each pixel subtracted from the other in the two images is then compared to determine if an athlete is present in the area. If the difference of the two images is greater than the threshold, then the value of "detect" is set to 1, indicating that there is an athlete present in the area. However, if the difference in the two images is not greater than the threshold, then the current image is set as the reference image and the value of "detect" is set to 0. This indicates that there is no athlete present in the detection area. The code then returns to the main functionality, Figure 9, and the value of the variable "detect" is sent out via LoRa.

This process is looped through continuously until the entire system is powered off. In other words, the detection subsystem will continue to complete the following steps: capture images, convert them to a greyscale image, convert them to a binary image, perform image subtraction, and then send the results out via LoRa to the uphill unit. This entire process will be done approximately every second. This will allow for the athletes on the hill to be aware of obstructions in the detection area as soon as possible, providing them enough time to register the change.

3.1.2 Detection Fabrication and Verification

The fabrication of this subsystem involved the two components, the Raspberry Pi, and the Raspberry Pi camera. Additionally, a PCB (Printed Circuit Board) was developed in order to allow for a seamless mount of camera to the Pi computer, Figure 12. This PCB acted as a shield on top of the Pi. As mentioned previously the camera communicates to the Pi through a 15-pin ribbon cable on a line called, CSI. These connections were all that needed to be made in order to implement the detection subsystem.

Figure 12: PCB Detection Subsystem Connection

In order to fabricate the code for the subsystem, MATLAB was originally used to perform the image subtraction, Figure 13. This method provided a proof of concept of the subsystem, before it was implemented on the Raspberry Pi. All of the image processing was first tested in MATLAB. The images were taken on the camera and Raspberry Pi, that would be used in the final result and then were loaded into MATLAB for processing. This initial testing allowed for a process to be developed for the final code. After the MATLAB code was proven successful the code was transferred to C code in order to be implemented on the Raspberry Pi.

Figure 13: Example of MATLAB Difference Images

Verification of the detection unit involved a set of low-level tests, isolated from the rest of the system. The purpose of these tests was to ensure that the specifications and requirements were able to be met at a lower level, so that they could be assumed to be met at a higher level with greater complexity.

The first verification to be performed, tested the accuracy of the detection unit. This test isolated the processing from the image capture and all other subsystems. There were preloaded images on the Raspberry Pi of a person entering the detection area and then leaving the detection area in front of the camera. The athletes entering and leaving did not need to be within the 30ftx30ft area, they just need to be seen in the camera or not seen. The Raspberry Pi was connected to power and a display in order to see the results of the tests. The person testing was then responsible for determining which frames had a person in them, and which were without a person. Those were then written down, and the testing code was run through. The person testing the code once again determined which of the frames were guessed correctly and which were not, Table 4.

Table 4: Raw Test Results of Detection Verification Test

	Expected Detection Signals	Actual Detection Signals
Test 1:	7	6
Test 2:	13	12

Test 3:	6	5
Test 4:	7	9
Test 5:	11	11
Test 6:	5	4
Test 7:	4	4
Test 8:	13	12
Test 9:	3	3
Test 10:	4	4

Using the data from the test, the accuracy of the processing was determined to be greater than 95%. As this was the threshold that was needed for the specification, Spec 1.1.2), this test proved to pass the verification.

A comparison was made between each set of frames. This compared the total frames to the correct guesses from the detection subsystem, Figure 14. The detection subsystem proved to guess correctly 96.5% of the time. However, since it was determined that, *Detection is defined as an object being in the frame for more than 2 seconds*, the accuracy in that case was 100%. This was due to the system catching the mistakes within a second of the changes.

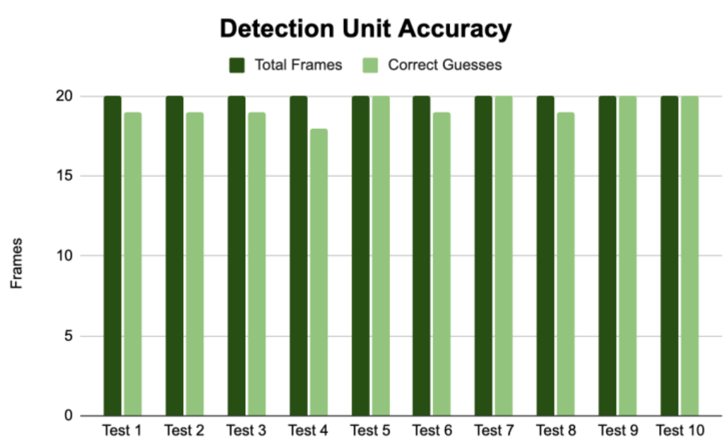


Figure 14: Detection Spec 1.1.2 Results Graph

This test was well within the margins of what was needed, and this meant the fabrication was successful and the next pieces could be integrated.

Another specification level test that was completed was the testing for Spec 1.1.1). This Spec referenced the size of the detection area. This Spec would determine the amount of the landing area that the detection area would cover. This specified that a 30ftx30ft area would be a part of the detection system's processing.

This test was setup with a 32ftx32ft square in front of the raspberry pi and camera, Figure 15. The purpose of this test was to ensure proper visibility of the detection area by the camera. In order to ensure that at the system level there would still be a margin for a working system, two feet was added to all sides of the square. This was to ensure that when more complexity and components were added to the subsystem it would still be able to see the area under the specification. The camera was also placed 15ft from the detection area, and 5ft above the ground.

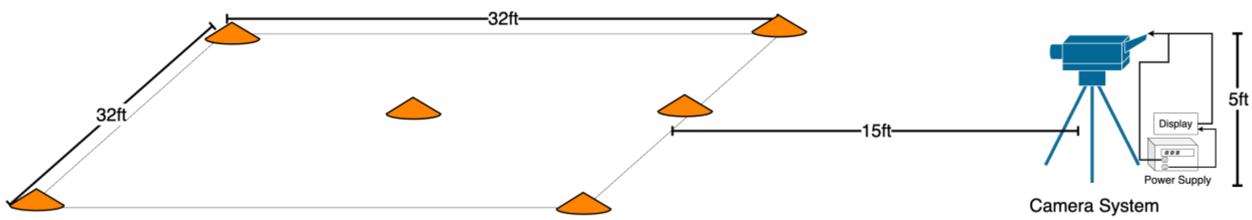


Figure 15: Testing Setup for Spec) 1.1.1

The raspberry pi and digital display were powered by the power supply. The raspberry pi desktop was seen on the screen, and this test used visual verification to ensure the entire square was visible. All orientations were in reference to the camera facing the area.

The subsystem was setup, and the Pi was powered on. The terminal of the Pi was opened, and the command, "***rpicam-still –preview***" was used to see what the camera was seeing. A participant was instructed to walk into the back corner of the square. This was meant to test the edge cases of the system. The tester then ensured that the participant was visible on the screen. That visualization was recorded, and the participant was instructed to leave the square.

Each orientation of the participant was recorded, Table 5. The person stood in the respective orientation until the tester could see what the camera was seeing and confirm that the participant was viewable using the current camera setup. If the tester could see the participant from the camera's display, then they would mark a yes in the table.

Table 5: Spec 1.1.1 Raw Data

	Orientation in the Area:	Participant's Visibility
Test 1:	Back Right Corner	Yes

Test 2:	Back Left Corner	Yes
Test 3:	Front Right Corner	Yes
Test 4:	Front Left Corner	Yes
Test 5:	Back Middle Edge	Yes
Test 6:	Right Middle Edge	Yes
Test 7:	Left Middle Edge	Yes
Test 8:	Front Middle Edge	Yes
Test 9:	No Participant Present	Yes

All orientations will be in reference to the camera facing the area

Given that all orientations were visible in the cameras view they can now be processed in images. The images will not be clipped or cropped in anyway so all viewpoints will be visible. Given that the verification for Spec 1.1.2) and Spec 1.1.1) were within the limits to move onto the next level of testing, it can be implied that at the Req level these tests would have also passed. Due to a failure in the Pi, and a lack of time the Req level testing was not completed. There was room within the Spec level testing for both Specs under the Req 1.1. The tests moved to system level testing in order to ensure that the system functioned as intended.

3.2 Subsystem 2: Signaling Unit [Ben Caba]

Figure 16 highlights the high-level block diagram of the signaling unit. The signaling unit acts as a liaison between the uphill athlete and the detection unit. The detection unit detects whether an athlete is present in the detection area of a terrain park jump and sends the status to the uphill processor. The uphill processor then uses that data to control a red and green light. When an athlete is in the detection area, the red-light illuminates, indicating to the uphill athlete that it is not safe to proceed. When no athlete is present in the detection area, the green light will illuminate, indicating to the uphill athlete that it is safe to proceed.

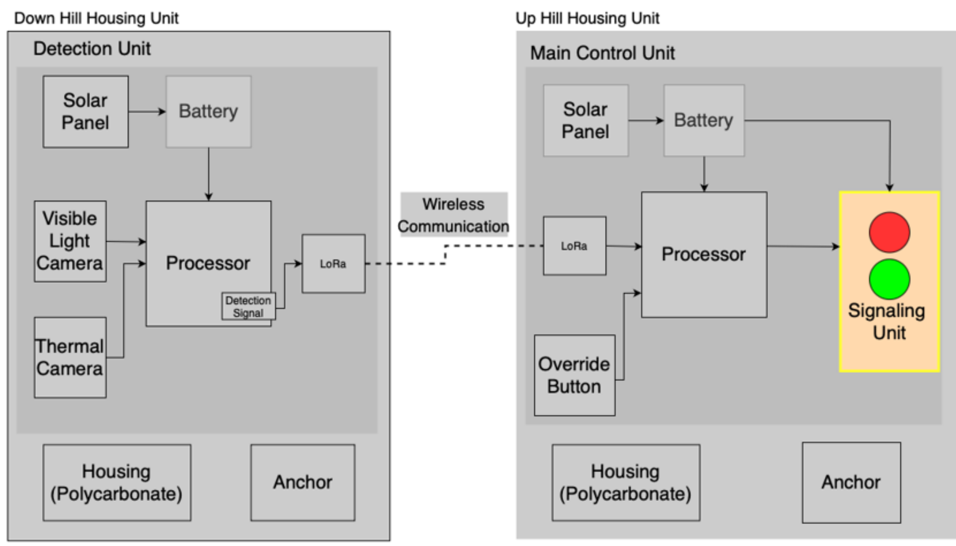


Figure 16: Signaling Unit High Level Block Diagram

3.2.1 Signaling Unit Design

The circuitry of the signaling unit is designed to utilize resistors, transistors, and LED lights, Figure 17. The anode of the PAR36 LEDs (labeled on green light) are connected to a +12V source, and the cathode (labeled on green light) of each light are connected to the drain of the IRLZ44NPBF NMOS transistors. The gate of each transistor will connect to an output pin of the MSP430 through a 1kΩ resistor. The green light circuit connects to P1.2, and the red light connects to P1.3 of the MSP430. The gate of each transistor is also connected to its respective source node through a 10kΩ resistor. The source node of each transistor is also connected to ground; this biases the transistor and allows the MSP430 to easily switch which light is on.

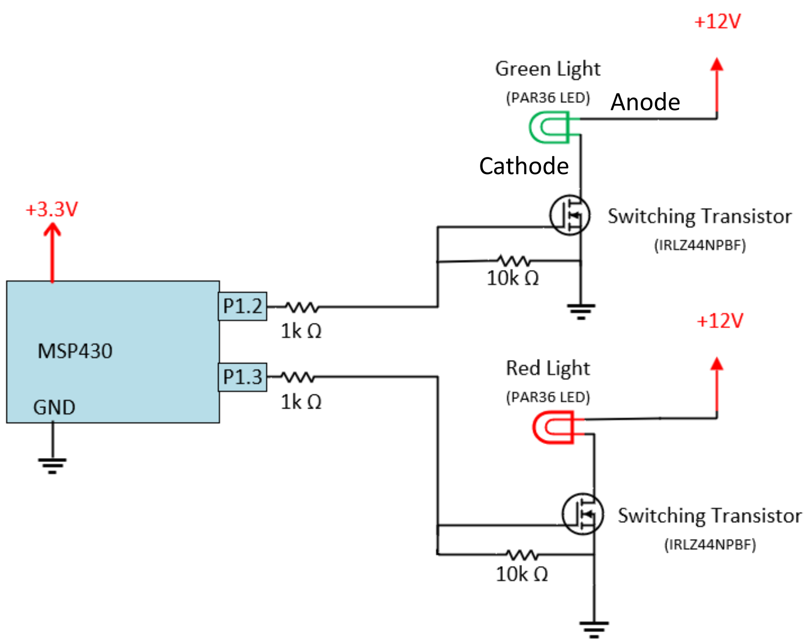


Figure 17: Signaling unit Final Circuit Diagram

Before discussing the design choices for the analog components of the signaling unit, it should be noted that the MSP430 is part of the communication subsystem but is depicted to display how the communication subsystem Integrates with the signaling unit. Additional details on the communication subsystem can be found in section 3.3.

NMOS transistors are utilized because of their quick switching speed and low power consumption. Resistors were placed to ensure current in the MSP430 output pins do not exceed the safe limit and risk causing damage to the processor [18]. The PAR36 LEDs were selected because Spec 2.2.2) demanded that both red and green lights produce a minimum of 1000 lumens. The selected PAR36 LEDs are rated to produce 1280 lumens, surpassing the 1000 lumen minimum.

The signaling unit circuit was then placed onto a PCB to allow for a simple method of mounting the circuit into the protective housing. Figure 18, the final revision of the signaling unit circuit PCB mounted inside the housing of the signaling unit. The PCB is mounted to an aluminum panel with screws and spacers. The spacers are used to ensure there is no contact between the transistor pins and aluminum panel. The lights connect to the PCB through wires that lead into screw terminals. This allows for an interface between the wires and PCB traces. Screw terminals are also used to connect both +12V and +3.3V power lines.

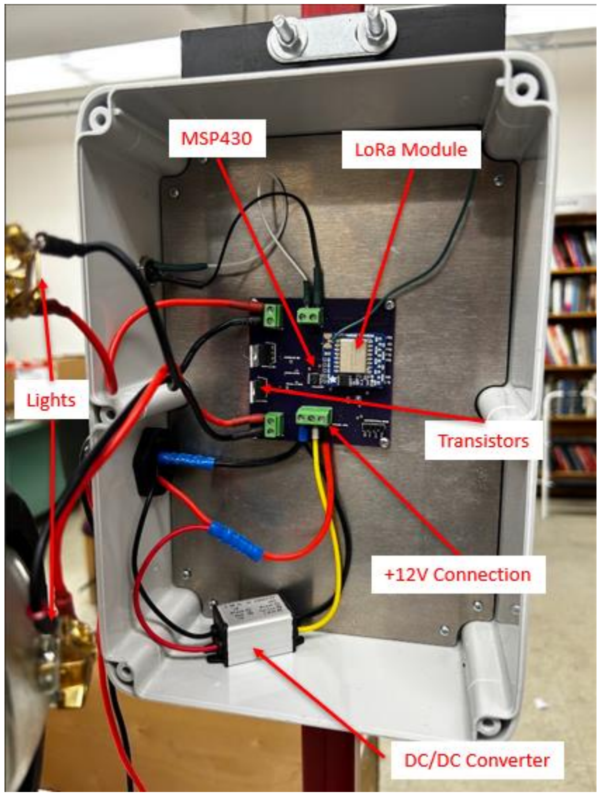


Figure 18: Signaling unit PCB

The signaling unit, as well as the communication subsystem, 3.3, are powered using a standalone power system, Figure 19. The standalone power system is a combination of a 50W solar panel and 12V LiFePo4 battery, regulated by an MPPT 75/15 charge controller. The Solar panel and battery connect to the charge controller through wires that connect to the built-in screw terminals. The load terminals then have wires that connect to the signaling unit and DC/DC converter.

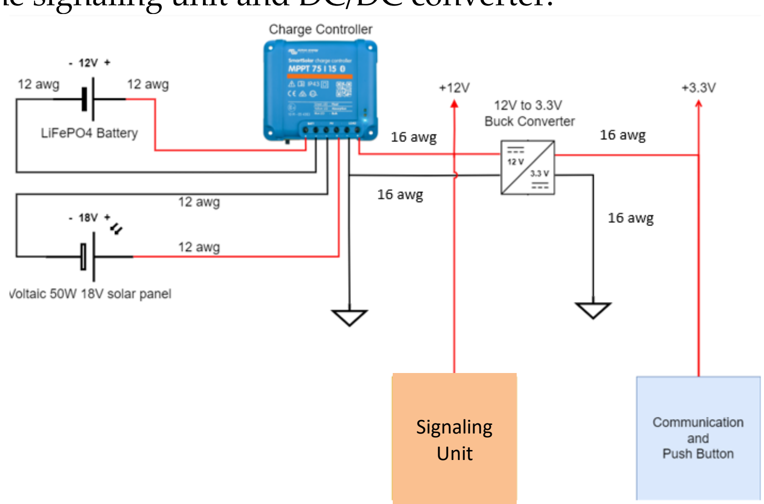


Figure 19: Uphill Power System Circuit Diagram

The charge controller has six total screw terminals: There are two terminals for the solar panel connection, two for the battery connection, and two for the load connection, Figure 20. The load terminals are what power the signaling unit, the connection from these terminals can be found in Figure 18, labeled as “+12V connection”. The wires that run from the “load” terminals also connect to a DC/DC converter, labeled “DC/DC converter” in Figure 18. The converter is used to step down the voltage and supply the communication system with +3.3V.

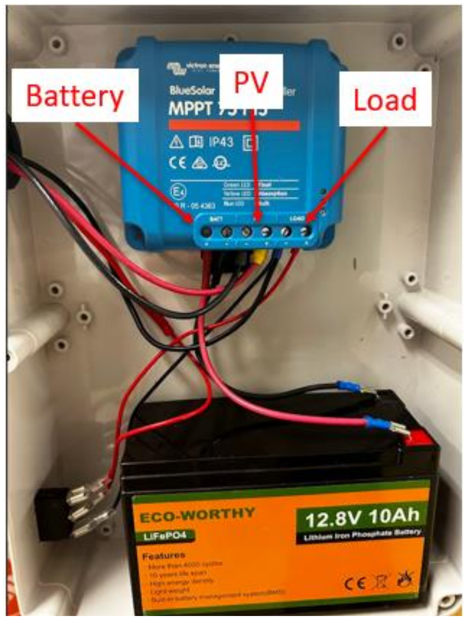


Figure 20: Charge Controller Wiring

3.2.2 Signaling unit Fabrication and Verification

The signaling unit is a crucial aspect of the overall success of the project. If the lights are not visible to athletes, they could be at risk of committing themselves to a jump when the detection area is not clear. Therefore, Spec 2.2.2) is crucial to ensure that the lights are bright enough, for athletes to see. Table 6, the required materials needed to verify the lumen count of each light.

Table 6: Equipment Needed for Testing Spec 2.2.2

Red Light
Green Light
12W power source
Tape measure

Lux Meter

The red and green lights were tested to determine each of their lumen count. The distance from the lux meter to the lights was measured using the tape measure. After accumulating all the gear required, the verification process was ready to begin.

The verification process for Spec 2.2.2) began with connecting the green and red lights to the battery. Each light was tested individually. Figure 21, the green light connected to a battery. The red light was connected in the same way, the only difference between the green and red light is the color of the illuminated light.

Figure 21: Green Light Connected to Battery

The next step in setting up the test was to place the lux meter a measured distance away from the light, Figure 22 shows the lux meter facing the green light. The center of the lux meter should be lined up with the center of the light to obtain the most accurate results. Note that the battery is not pictured, this is simply because when the image was taken the battery used banana cables to connect to the light causing the battery to be out of frame.

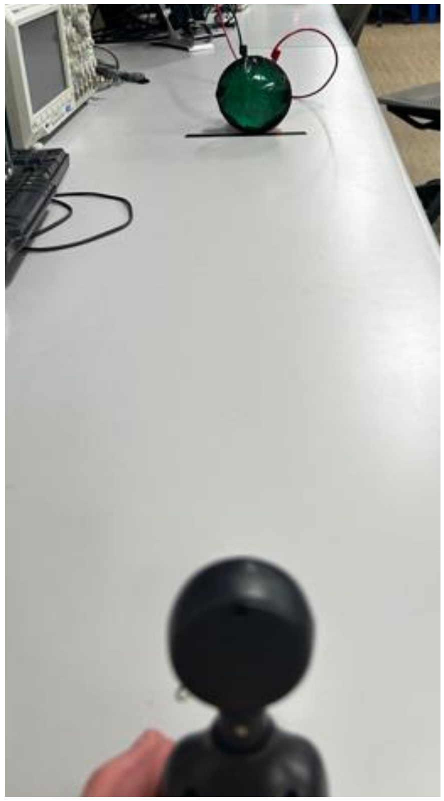


Figure 22: Lux Meter Facing light

With the setup ready, the verification procedures were ready to be executed. Following is a concise list of steps to measure lumen count for each individual light, as well as results from when this test was conducted.

Test procedure:

1. Measure distance between light and surface in meters (D), record this value
2. Multiply D by tan (60˚), this is the radius (R) of the light's beam onto the surface
3. Square R and multiply by pi, this is the area (A) the light covers in square meters
4. Place lux meter on surface light will shine on
5. Record lux value (L1)
6. Turn on power supply or connect battery
7. Record lux value (L2)
8. Subtract L1 from L2 (L)
9. Multiply L by A
10. Record lumen value to table
11. Repeat for other light

Test Results:

Table 7 displays the measurements of the distance between the lux meter and light (D), the radius of the beam (R), the area of the beam (A) at the distance (D), the lux count of the environment (L1), the lux count of the environment and light (L2), the lux count of the light (L), and finally the total lumen count of the light which is (L x A).

Table 7: Measurements for verification of spec 2.2.2

	Distance (D)	Radius (R)	Area (A)	L1	L2	L	Total Lumens
Green Light	0.27 m	0.46 m	0.67 m^2	0.8	1966	1965	1317
Red Light	0.27 m	0.46 m	0.67 m^2	0.0	2592	2592	1737

The results proved that both the red light and green light could supply well over the desired 1000 lumens. It should be noted that this trial was conducted while all lights in the lab room were off, possibly inflating the lumen count because of the dark environment. So, the test was conducted again with the lights of the lab room on to verify this was not the case.

shows results of the second test when the lights in the testing room were on, the same measurements from Table 7 were recorded.

Table 8: Test 2, lights on in the testing room

	Distance (D)	Radius (R)	Area (A)	L1	L2	L	Total Lumens
Green Light	0.27 m	0.46 m	0.67 m^2	350	2361	2011	1348
Red Light	0.27 m	0.46 m	0.67 m^2	380	2805	2425	1626

Results of the second test showed that the lights were able to produce the minimum lumen count of 1000. Now under a more realistic setting, the lights proved to successfully supply the correct number of lumens. As the JumpGuard system is intended to operate outdoors, the second test proved that both lights are sufficiently bright for athletes to see.

3.3 *Subsystem 3: Communication Subsystem [Riley Holmes]*

Figure 23 shows the high-level block diagram of the communication subsystem. The communication subsystem includes the LoRa modules in both the uphill and downhill units, as well as the uphill processor and override button. The main purpose of this subsystem is to wirelessly transmit the detection signal from the downhill unit to the uphill unit and control the signaling unit, considering the override button.

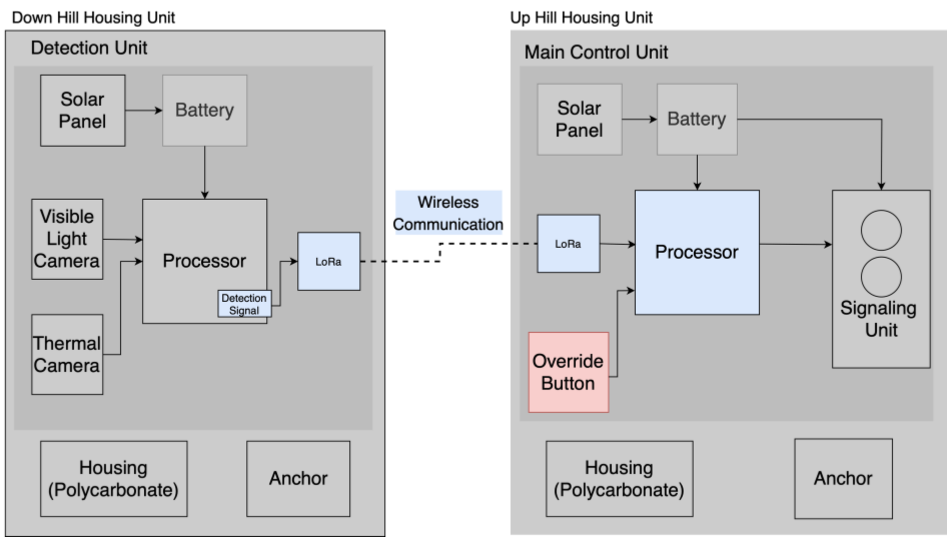


Figure 23: Communication Subsystem Block Diagram

3.3.1 *Communication Design*

Figure 24, the finalized circuit diagram for the communication subsystem. On the left is the downhill unit, with the downhill processor, a Raspberry Pi 4, connected to the LoRa module, RFM95W. These two devices connect to each other via the serial peripheral interface (SPI) and a reset pin. These are how the devices communicate to each other and allow the data to be transmitted. The Raspberry Pi is powered by the standalone power system, needing 5V to operate. The LoRa module needs 3.3V to operate and is supplied by the Raspberry Pi's 3.3V output pin.

The uphill unit uses the same SPI connection and reset pin to connect the MSP430FR2111 to the LoRa module, RFM95W. The MSP430 has an interrupt on P2.1, that is connected to the push button circuit. The push button circuit has one side of the button connected to 3.3V, with the other side connected to P2.1 of the MSP430, with a pull-down resistor of 10K Ω. The uphill unit has a power stability circuit as well, consisting of 2 capacitors in parallel, 10uF and 0.1uF, connected to power and ground. The outputs to the signaling units are P1.2 for the green light and P1.3 for the red light. The circuit connected to these pins are covered in section 3.2.

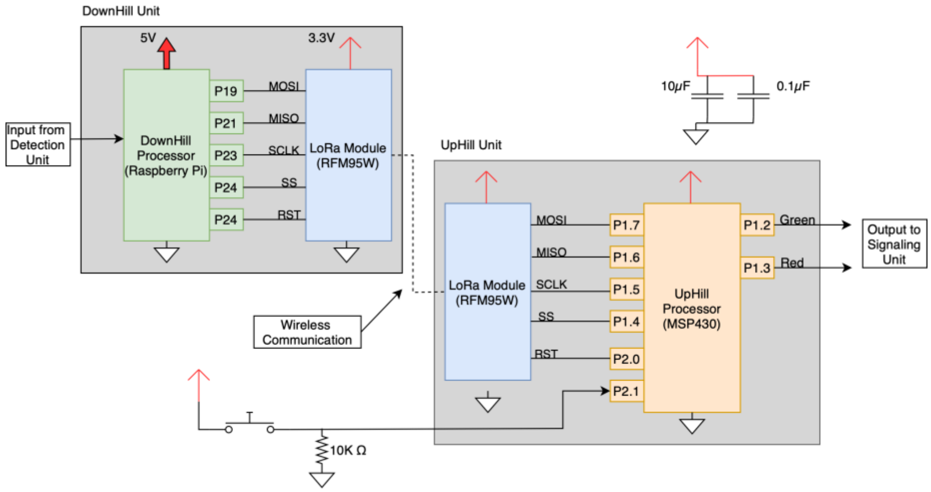


Figure 24: Communication Subsystem Circuit Diagram

To fully understand this design, the flowchart for the software on each processor is needed. Figure 25 is the flowchart for the Raspberry Pi. The code implemented on the Raspberry Pi is a Python program. This program gets called when the detection unit has an updated detection signal. The program first initializes SPI communications. The code then calls the LoRa Init function (see Figure 27) to initialize the LoRa module. The important parts of initializing the LoRa module includes setting the frequency to 915MHz and setting the FIFO register addresses. The code then enters the main loop, which sends the data, then returns to the detection program.

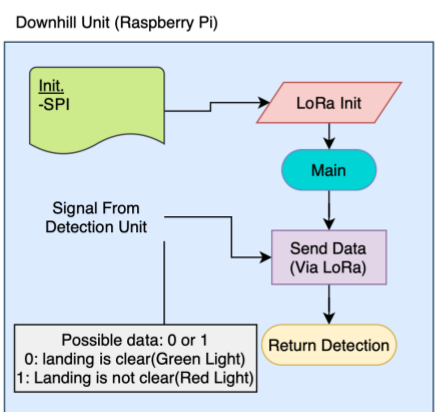


Figure 25: Downhill Unit Software Flowchart

Figure 26 is the flowchart describing the code in the uphill unit, on an MSP430FR2111 microcontroller. The code on the MSP430 is a C program. To start, the code initializes SPI, sets P1.2 and P1.3 as outputs for the signaling lights, and sets P2.1 as an interrupt for the push button. The code then calls the LoRa Init function (see Figure 27) to initialize the LoRa module. The while loop, where all the data processing is handled, waits for a LoRa signal to be received. It then checks a flag called emergency which holds the status of the emergency button. If the emergency flag is set (equal to 1), the system turns the red light on. If the emergency flag is not set (equal to 0), the code then checks the data it received from the LoRa signal and changes the lights accordingly. If the push button is pressed, it triggers the P2.1 interrupt, which toggles the emergency flag and clears the interrupt flag.

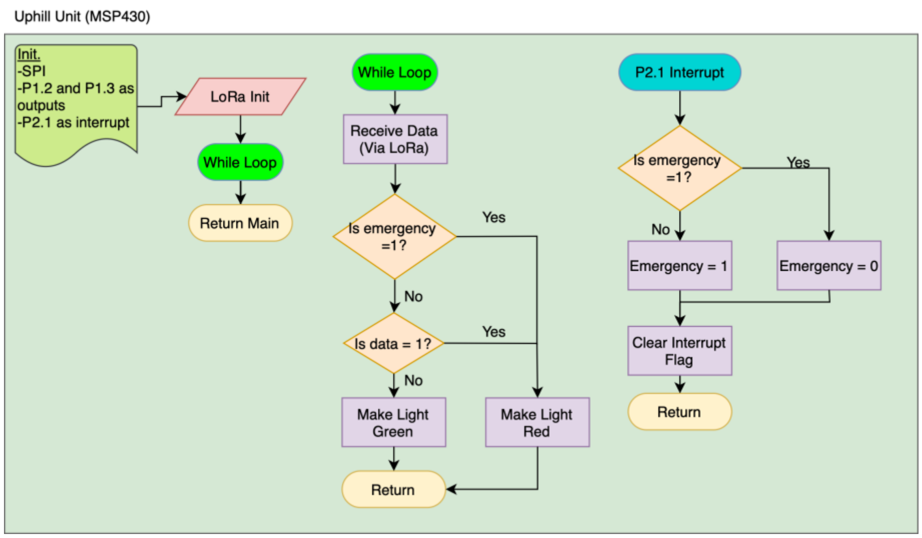


Figure 26: Uphill Unit Software Flowchart

Figure 27 shows the LoRa initialization function. It first starts by checking the ID register (0x42) of the LoRa module. This ensure connection and operation of the LoRa module, as well as verifies the correct LoRa module version is being used. If it's not the correct version, the code stops running. This is because the code cannot ensure proper functionality with a different LoRa module. If the module is of the correct version, the processor then puts the module into LoRa/sleep mode, the only mode in which the module will accept its settings being changed. The module is then setup, with the important parts being setting the frequency to 915 MHz and setting the FIFO register pointers to the correct position. The frequency is set to 915MHz to comply with FCC regulations. The FIFO register pointers are set so the module knows where to add and read data for transmission and reception.

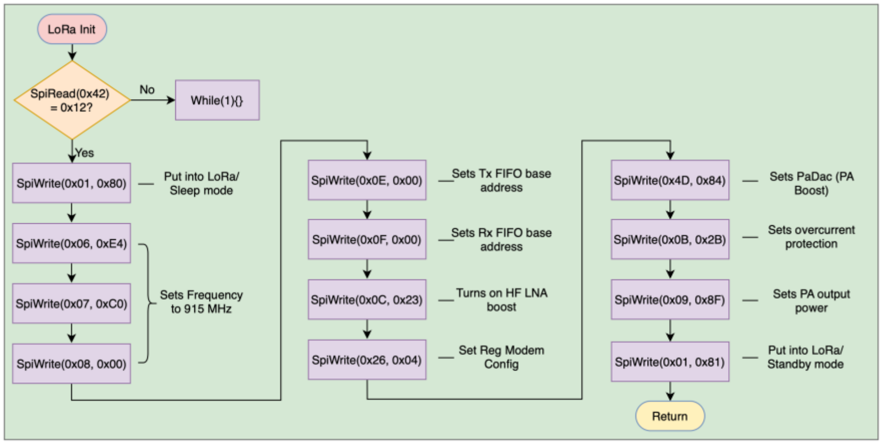


Figure 27: LoRa Init Function Flowchart

3.3.2 *Communication Fabrication and Verification*

To begin fabrication, the first step was to verify the operation of the LoRa modules by connecting the modules to two Arduinos and use the premade libraries. Figure 28 shows the circuit diagram. The premade libraries used are publicly available, made by Sandeep Mistry [19]. The library sends a signal once every 5 seconds and is meant to be used to verify the modules are working.

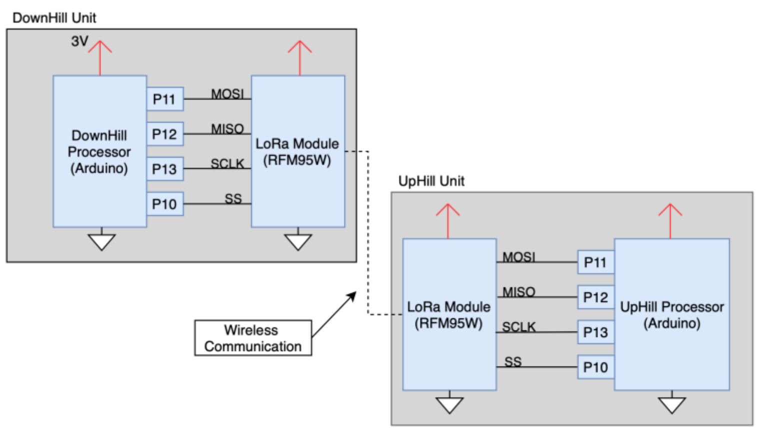


Figure 28: Verification of LoRa Modules Circuit Diagram

After the LoRa modules proved functional, the next step was to code the MSP430 and the Raspberry Pi to connect to the LoRa module. The circuit diagram for how this was connected is Figure 24.

Once the code was successful in communicating to the LoRa module and receiving data, a set of low-level testing was performed on the subsystem, isolated from the rest of the system. This was done to verify the subsystem met specification and requirements at the lowest level, ensuring operation before integration with other subsystems.

An example of a low-level specification test was to test spec 1.2.1 stating the latency from when the sensor triggers, to when the signaling unit triggers must be ≤0.5s. Figure 29 shows the circuit diagram for this test. To perform this test, the Raspberry Pi code was modified to flash pin 26 right after a signal is sent. The MSP430 code was modified to flash the green led when the signal was received. Using an Analog Discovery 2, a mobile oscilloscope tool that connects to a computer. The Raspberry Pi was connected to channel 1, and the MSP430 was connected to channel 2. Using the oscilloscope's logging function, a .csv file was saved every time channel 1 went high, every time a signal was sent. This captured the exact time stamps that each signal when high. The Raspberry Pi send a LoRa signal every half second. This ran for 1 hour, totaling 7200 samples. A python script was created to extract the code from every .csv file.

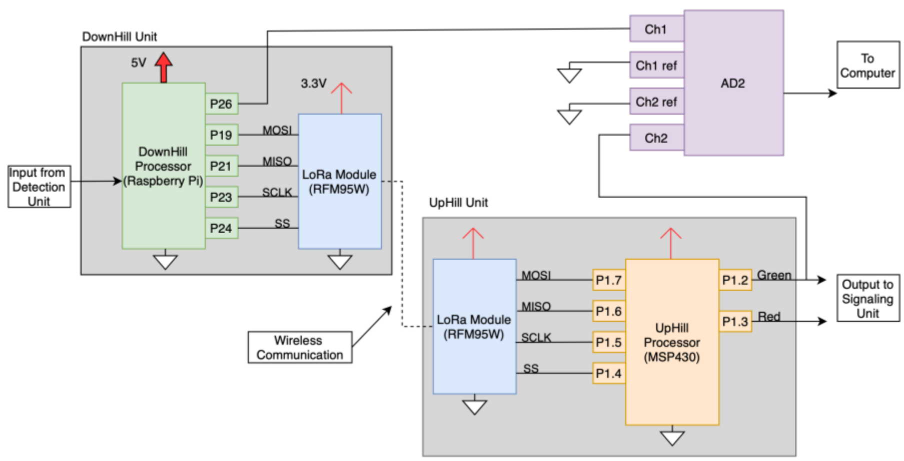


Figure 29: Spec 1.2.1 Test Circuit Diagram

Figure 30 shows the results of spec 1.2.1 testing. As can be seen, every sample is far below the spec cutoff of 0.5s, with every sample being under 0.1s. This test proved the system was ready for further requirement level testing and integration with other subsystems.

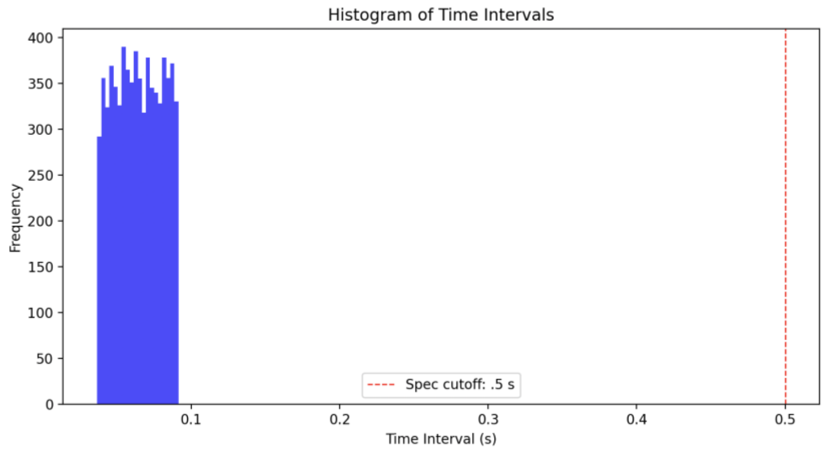


Figure 30: Spec 1.2.1 Testing Results

Requirement 1.2 was tested next. Req 1.2 states that the system must communicate the detection results to uphill athletes. Figure 31 shows the circuit diagram for this test. This test consisted of the completed uphill unit, as well as the Raspberry Pi, used to simulate the detection results. The Raspberry Pi sent a signal roughly every second, flashing an LED when the signal was sent. The uphill unit was places 60 feet away from the Raspberry Pi. Using a phones camera to record both the LED attached to the Raspberry Pi and the signaling unit, the latency was recorded from the time stamps of each frame.

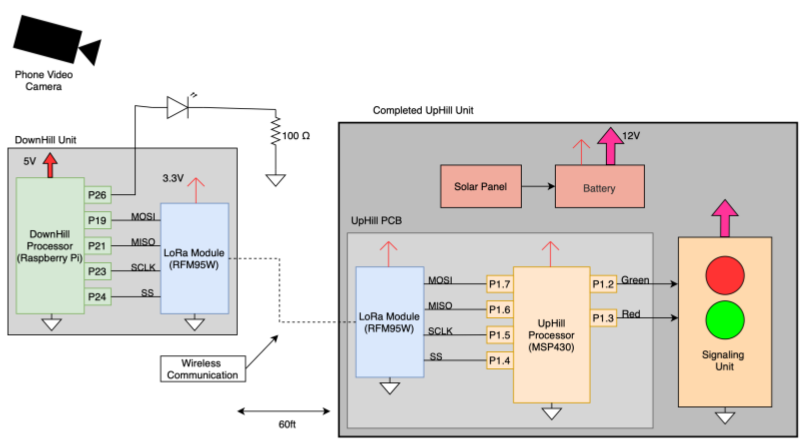


Figure 31: Req 1.2 Test Circuit Diagram

Table 9 shows the results of testing Req 1.2. The latency greater that what was seen on spec 1.2.1 testing. This is for a few reasons, the capacitance of the LEDs charging before light is displayed, as well as the inaccuracy of the time stamps of the video. The system still performed, far below that the 0.5 second spec needed. This test gave us the confidence to move forward with system level testing and further integration.

Table 9: Req 1.2 Testing Results

Trials	Time of Rasp. Pi LED (s)	Time of signaling unit turning on (s)	Time difference (ms)
1	.21	.29	80
2	1.25	1.33	80
3	2.29	2.38	90
4	3.32	3.42	100
5	4.37	4.40	30
6	5.4	5.47	70
7	6.44	6.54	100
8	7.47	7.57	100
9	8.51	8.62	110
10	9.55	9.60	50
11	10.58	10.65	70
12	11.63	11.70	70
13	12.66	12.76	100
14	13.70	13.81	110
15	14.73	14.77	40
16	15.76	15.83	70
17	16.79	16.88	90
18	17.83	17.94	110
19	18.88	19.00	20
20	19.92	19.97	50

3.4 Subsystem 4: Housing [John Podgorney]

The housing subsystem consists of the casings for both the detection and signaling units, along with the respective batteries. The main purpose of this subsystem includes dealing with all the aspects of weatherproofing, adjustability, and room / sizing for specific components. This can be seen in Figure 32, where the majority of components are seen within the housing block.

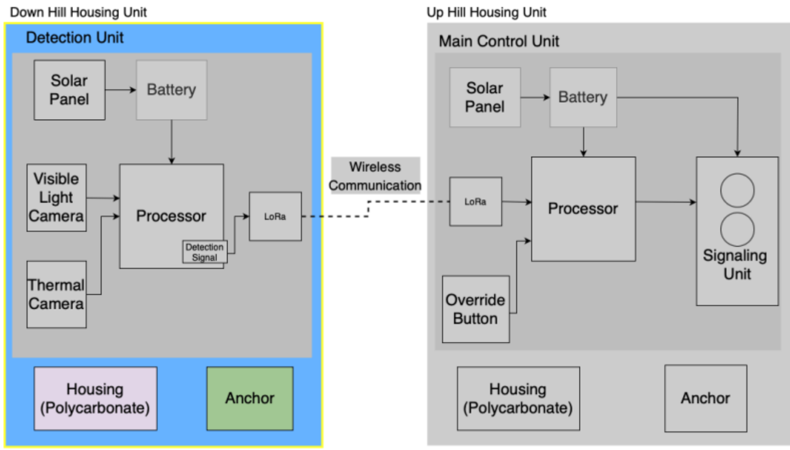


Figure 32: Housing System Block Diagram

3.4.1 Housing Design

The design of the housing system consists of two major parts: the uphill housings and the downhill housings. The housings needed to vary from each other, as both units required different sizing for the different components mounted within. Each unit consists of two cases, one for the battery and another for the unit's specific function. These cases were modified to allow for wiring, on / off switches, and the override button.

An alternatives analysis was performed to assist picking the right material. Between the options of ABS, polycarbonate, aluminum, and fiberglass, it became clear the polycarbonate was the option best suited for the project. The low cost and ability to handle loading and temperatures made it stand out as the material of choice, shown in Table 10.

Table 10: Housing Alternatives Analysis

	Weight	ABS	Polycarbinate	Aluminum	Fiberglass
		$8	$14	$31	$32
Cost	2	5	4	2	2
		-4°F	-20°C	-90°C	-40°F
Temperature Resistance	4	2	4	5	4
		5660 Psi	8500 Psi	165MPa	22kpsi
Structural Strength (Yeild Strength)	3	2	3	5	4
		3D printing, Injection Molding, CNC	High Temp 3D Printing, Injection Molding, CNC, Thermoforming	CNC, Die Casting, Extrusion	Pultrusion, Compression Molding
Ease of Manufacturing Customization	5	5	4	2	1
Totals		49	53	49	37

From there, the sizing of components that needed to be mounted was determined and cases were picked from those dimensions. The picked cases were then modified to allow holes for the aforementioned wiring and switches. Both battery housings (Figure 34 and

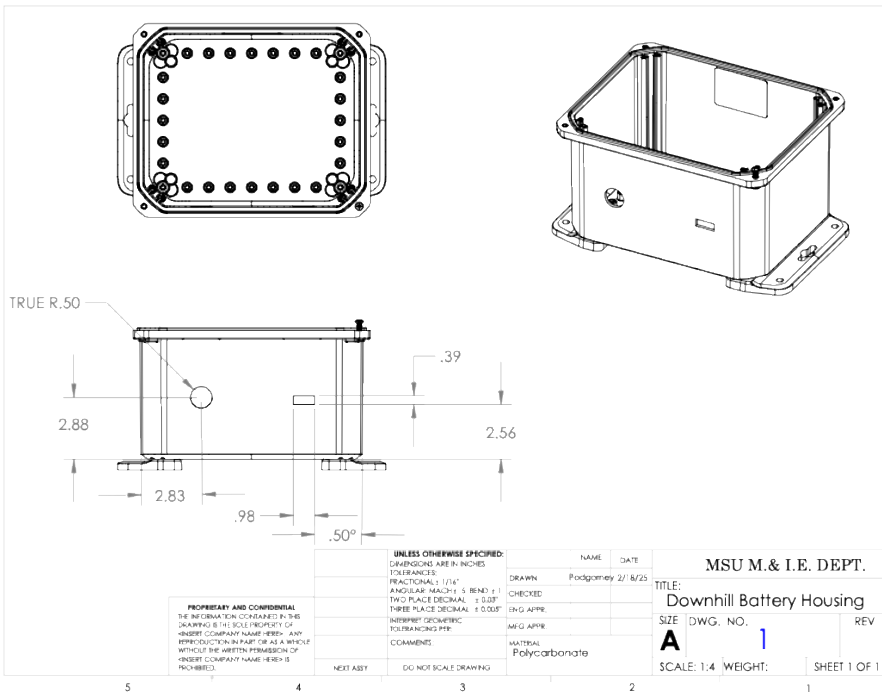
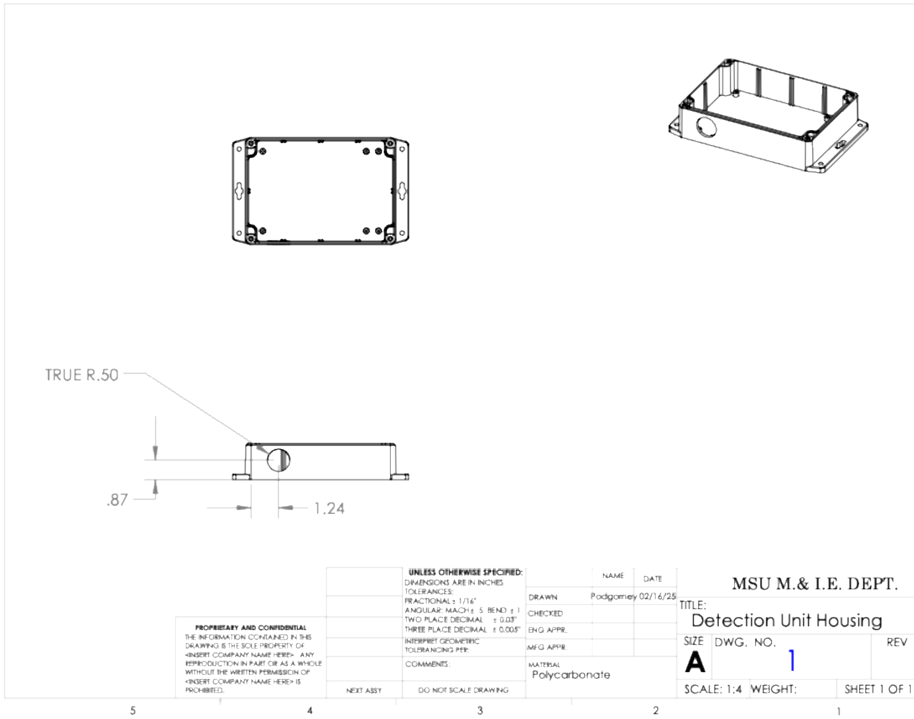


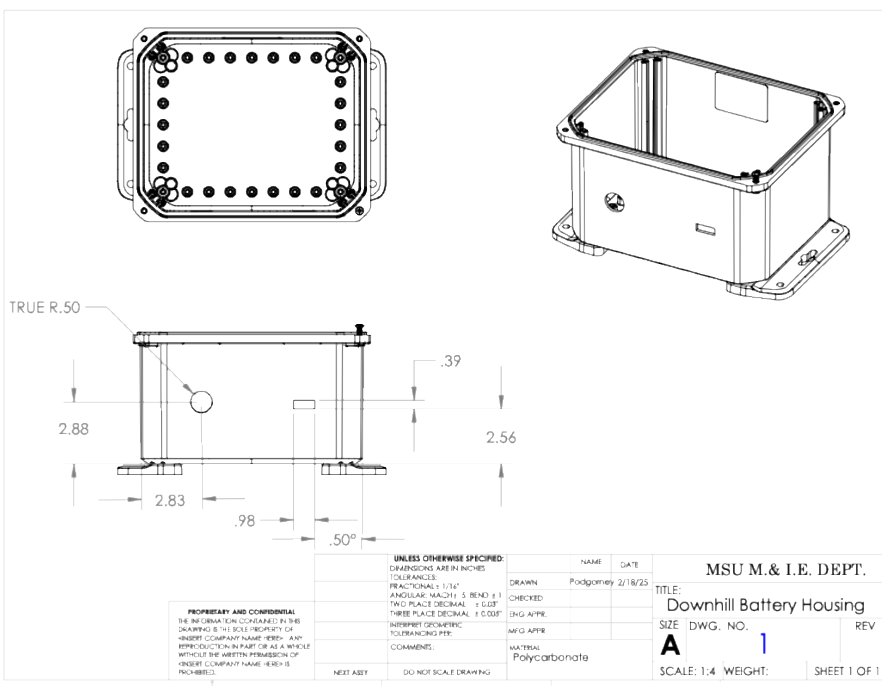
Figure 36) are larger to allow room for the batteries, charge controllers, and on / off switches. In the signaling case (Figure 33), two holes are present, one for wiring and the

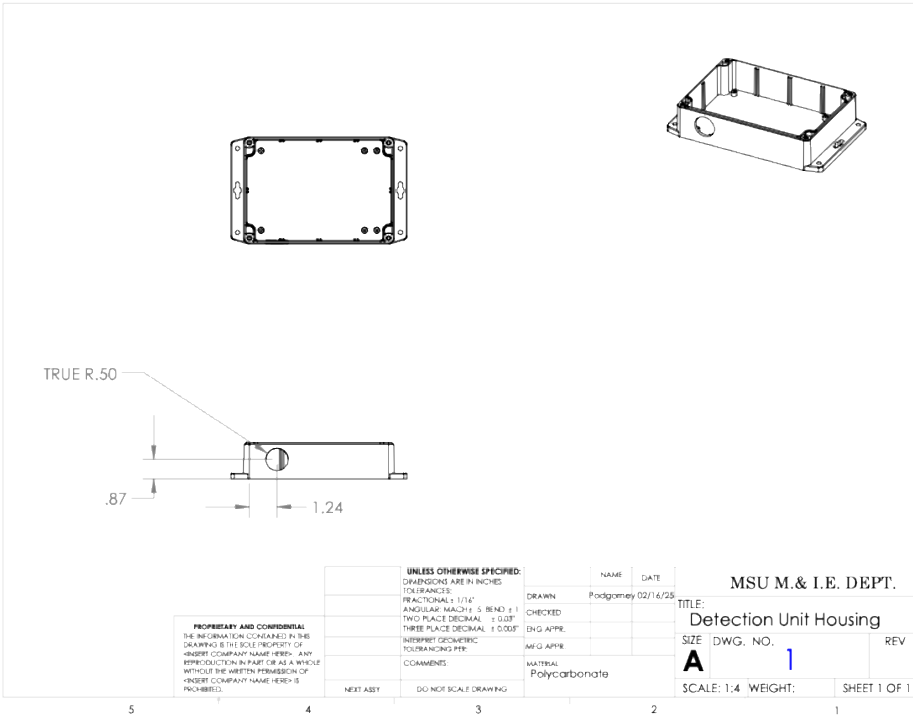
other for the override button, a constraint given at the start of the project. In the



detection case (

Figure 35), the only hole present is for the wiring.





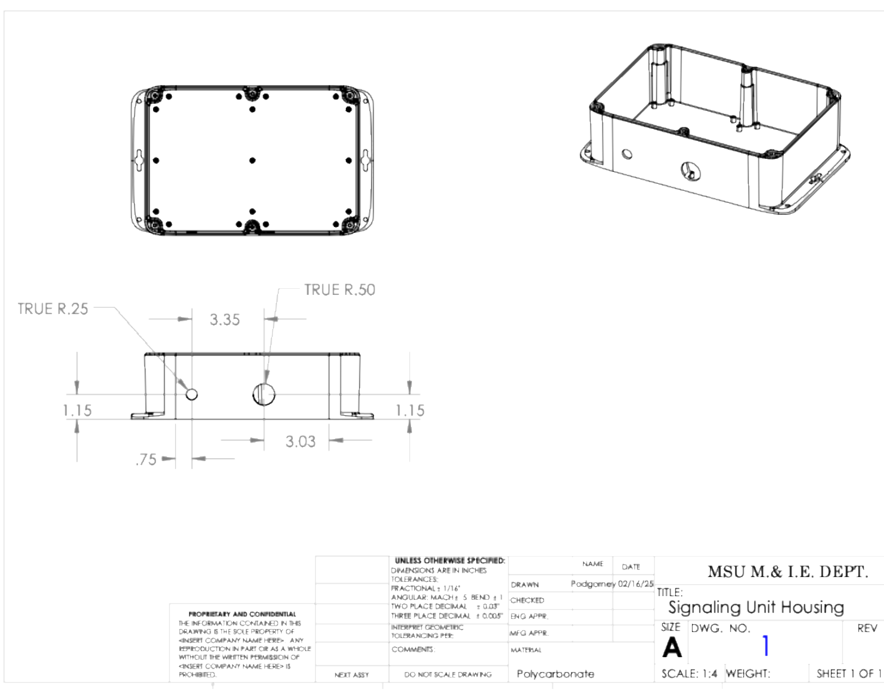


Figure 33: Uphill Signaling Unit Housing

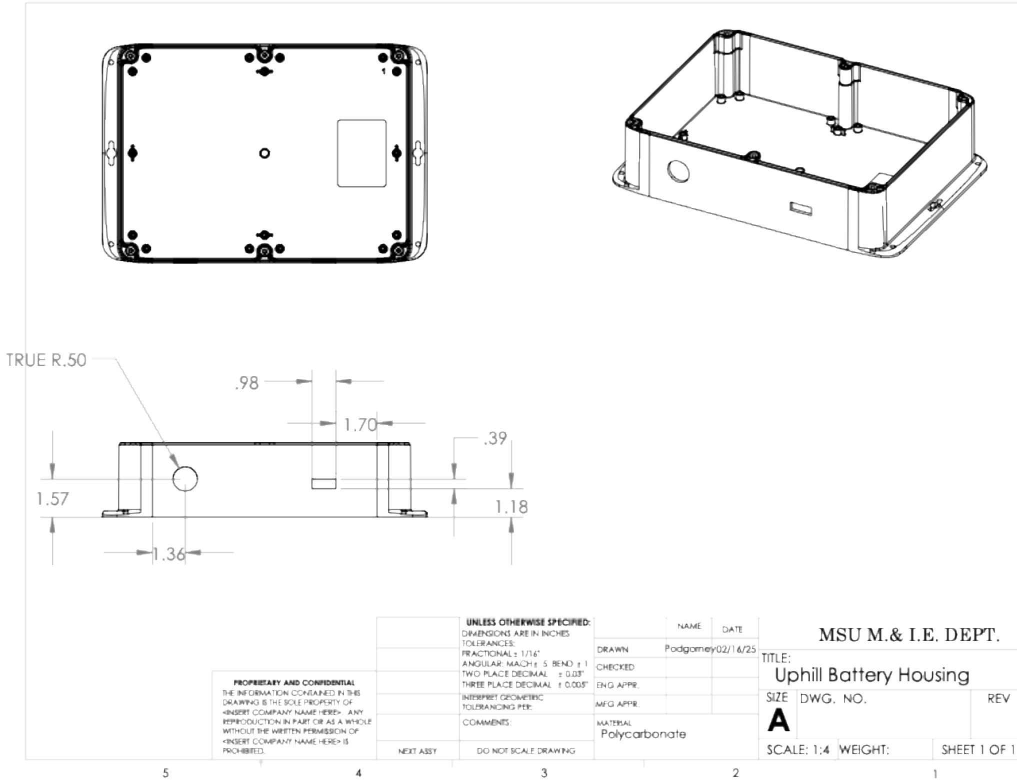


Figure 34: Uphill Battery Housing

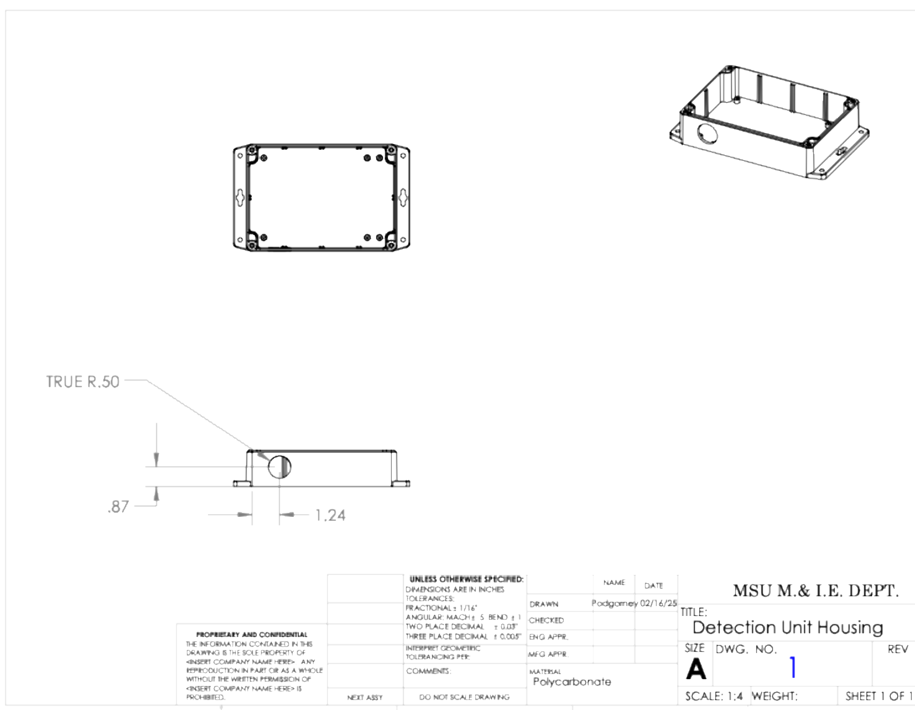


Figure 35: Downhill Detection Unit Housing

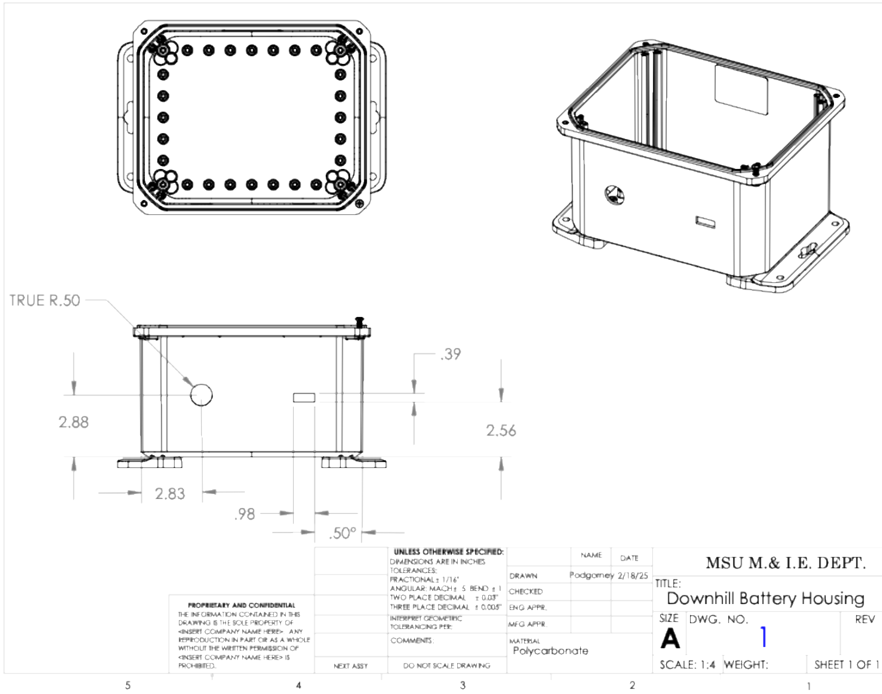


Figure 36: Downhill Battery Housing

The holes for the wiring were designed for specific wiring glands, allowing the housings to remain watertight while having things go in and out of the case. The same thing applies to the switches and buttons, where the holes were designed precise enough to ensure them being watertight while allowing enough room to fit the component.

To help integrate the housing and mounting systems, brackets were made for the housings to mount onto the PolyStakes. Sheet aluminum was made into 2 brackets for each housing, one for the top and another for the bottom. The constructed aluminum brackets were designed to integrate with their specific case, as the holes on the bottom attach to the cases without additional machining (

Figure 37, Figure 38,

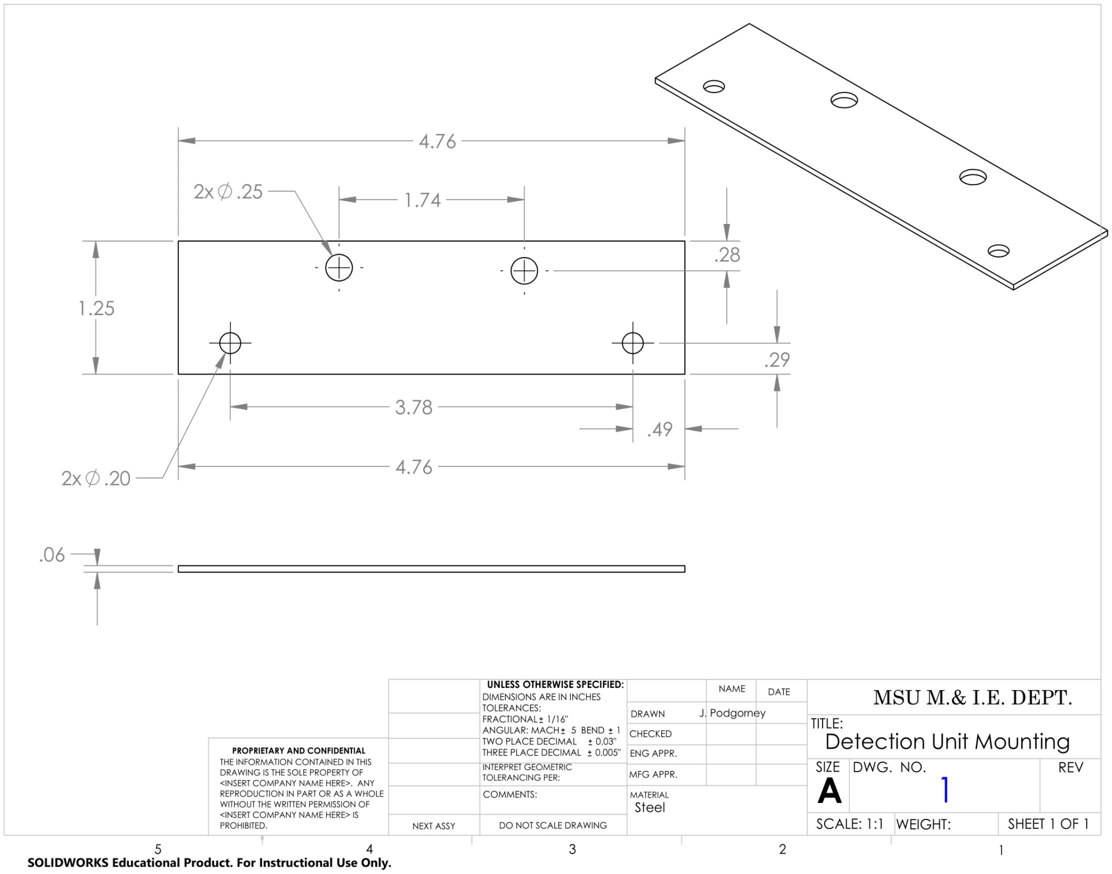


Figure 39, and

Figure 40). This helped maintain the integrity of the case while efficiently mounting them to the stake.

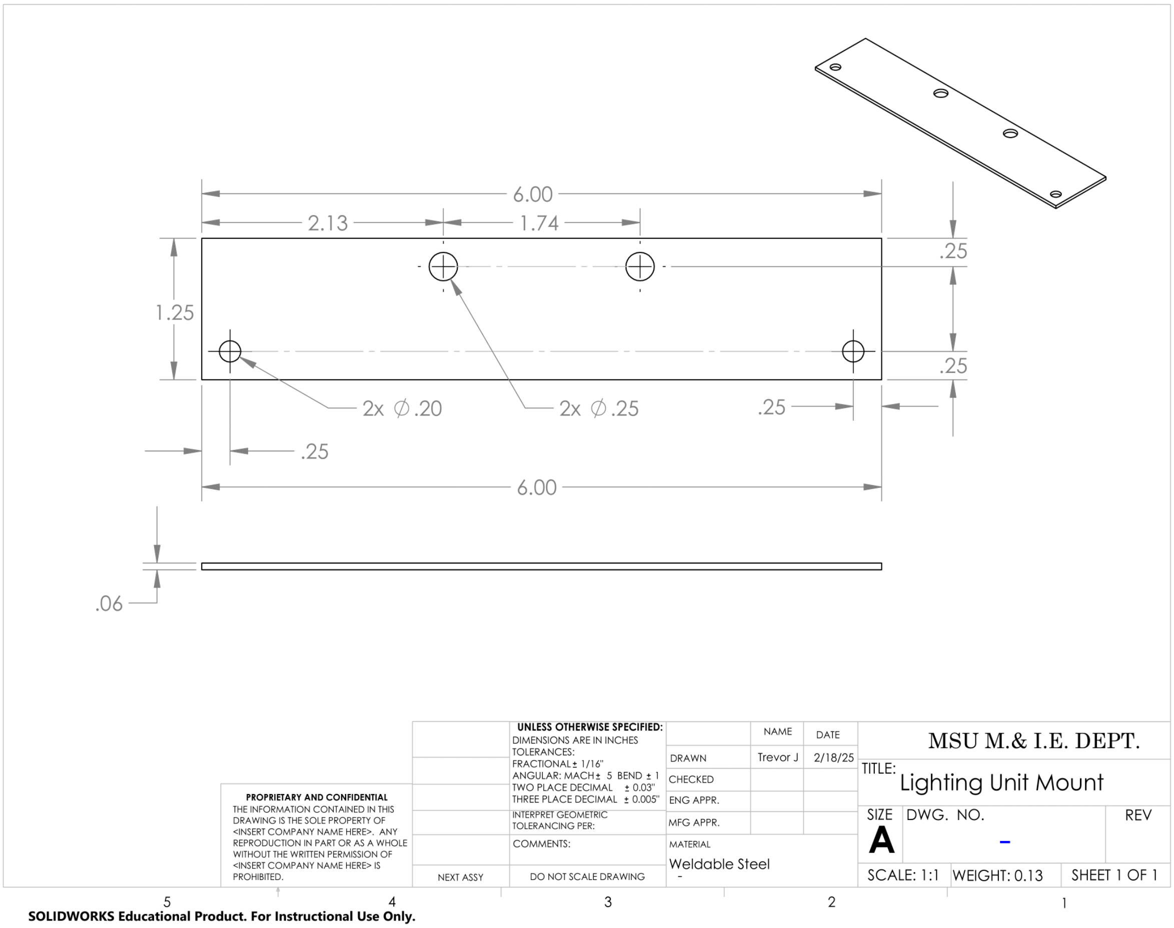


Figure 37: Signaling Unit Housing Mount

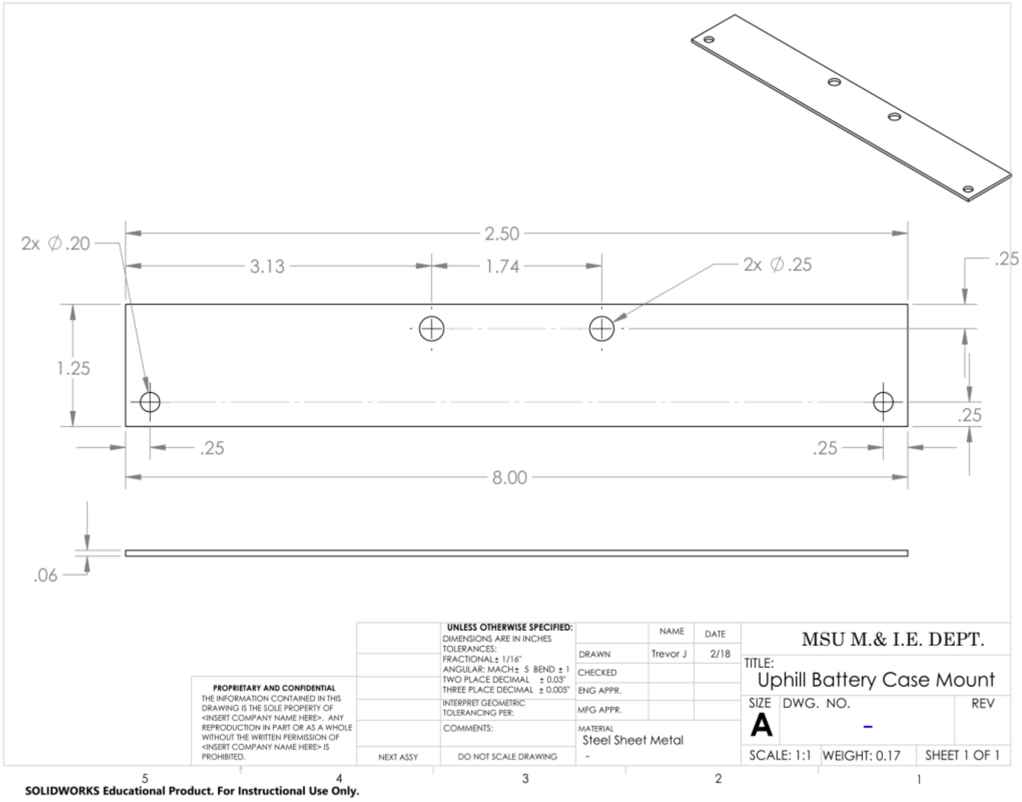


Figure 38: Uphill Battery Housing Mount

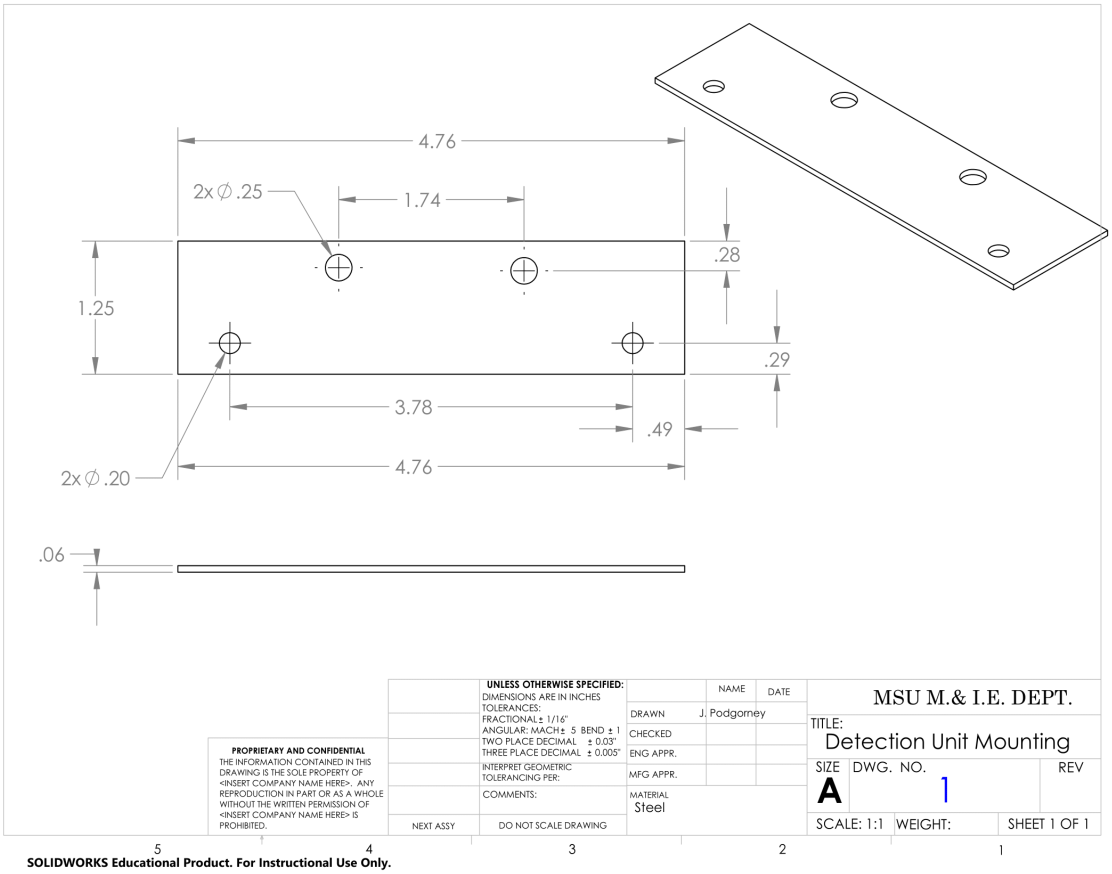


Figure 39: Detection Unit Housing Mount

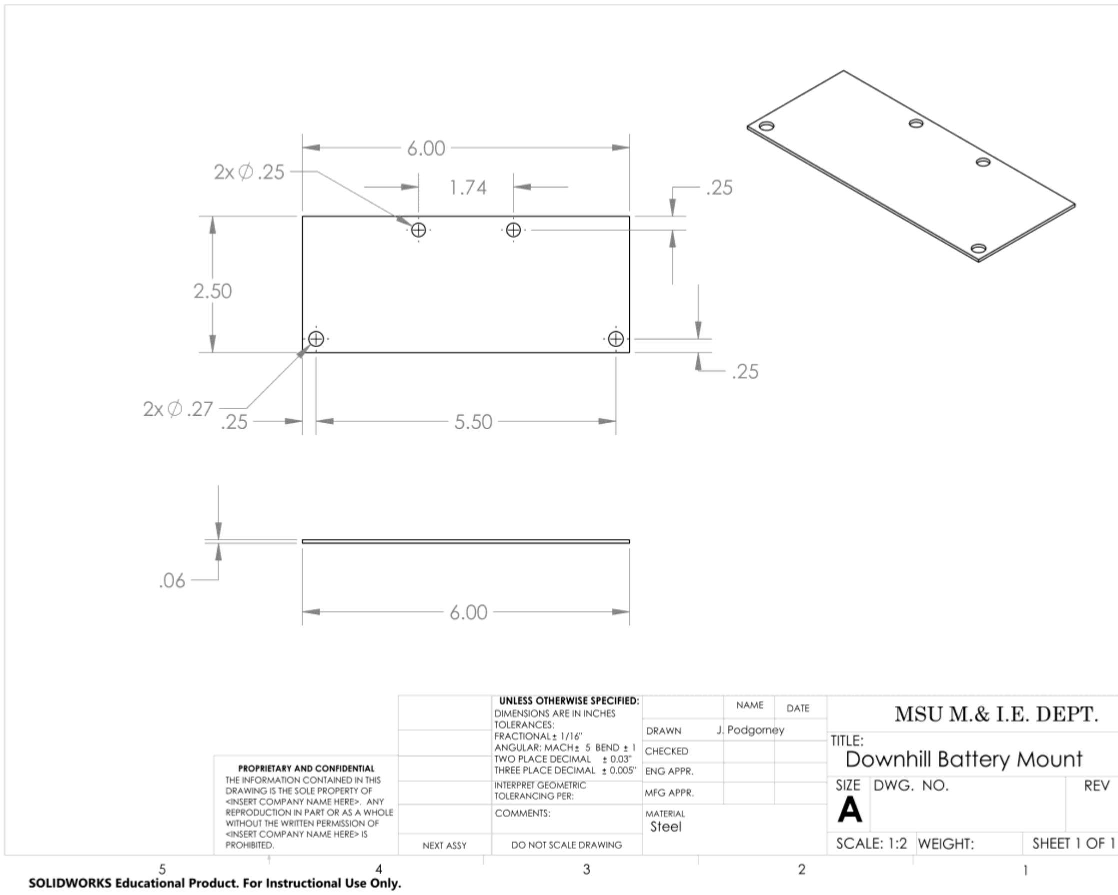


Figure 40: Downhill Battery Housing Mount

The last critical design portion for the housings was their internal mounting plates. The detection case and the signaling case both possess an internal plate that allowed for the mounting of electronics and other necessary components within. Both plates were designed such that the main processor in each unit could be mounted in a location that didn't interfere with other components. In the detection mounting plate, the holes were made so the Raspberry Pi would have enough room for the power wires and charge controller, making sure wires did not fail within the system (Figure 41). For the signaling mounting plate, the holes were also centralized, as this was the best spot to keep the MSP430 out of the way of other components (Figure 42).

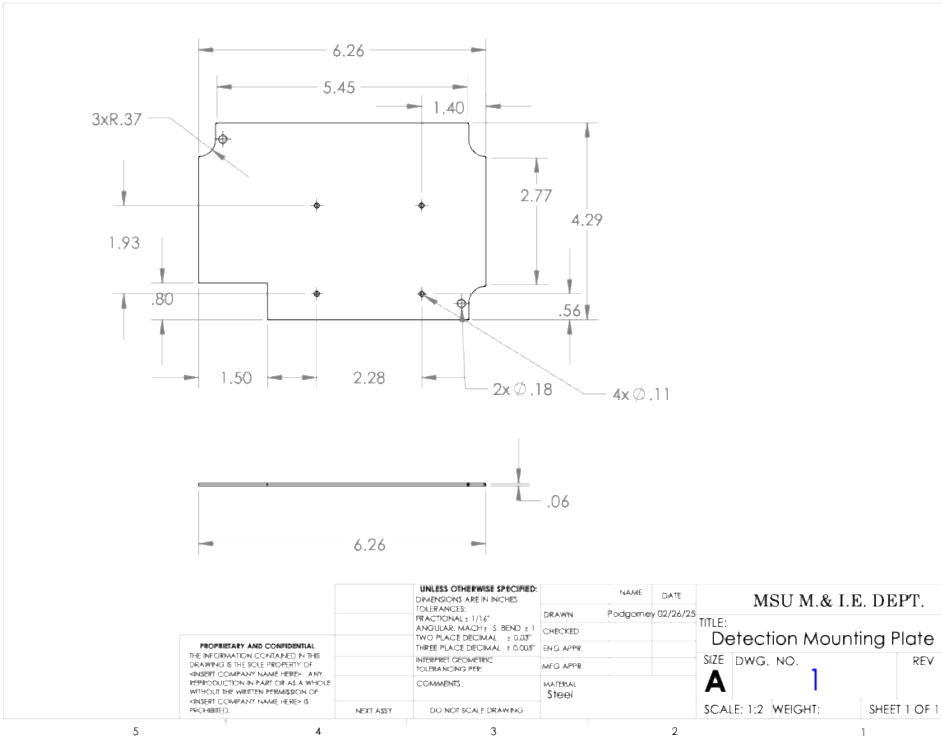


Figure 41: Detection Unit Internal Mounting Plate

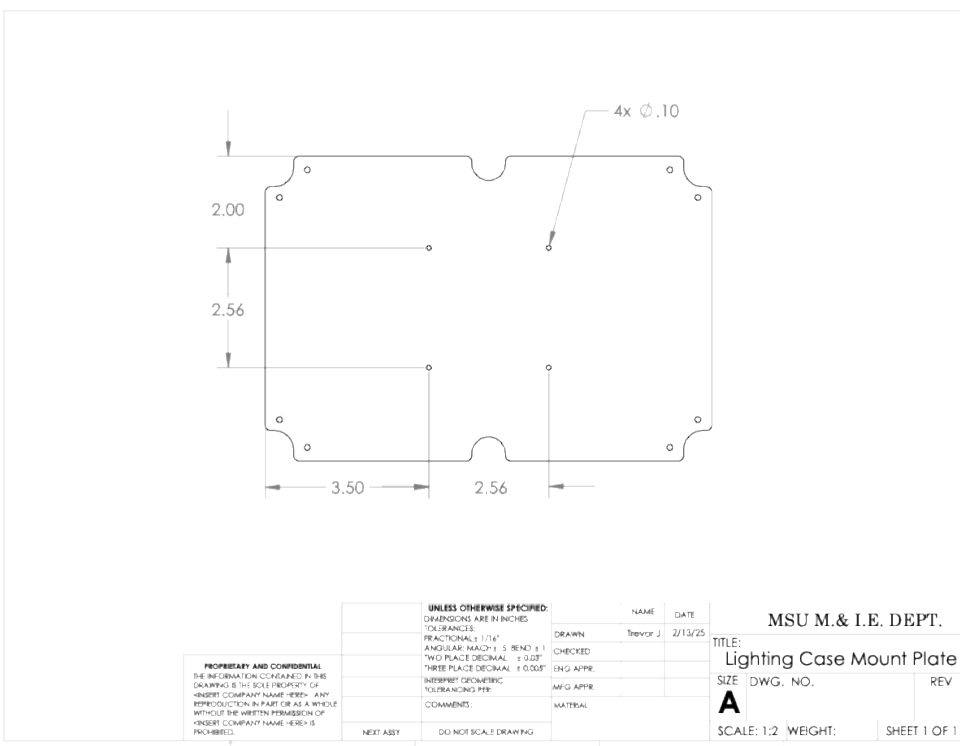


Figure 42: Signaling Unit Internal Mounting Plate

3.4.2 Housing Fabrication and Verification

The fabrication of the housing system began relatively simple. The first verification performed was just to verify that all the components could comfortably fit within their respective cases. After placing all the components withing the housings, it was determined that it was okay to continue to further fabrication. From there, the risk of the clear polycarbonate cover losing visibility due to fogging, freezing, or condensation in low temperatures was addressed. This test alone is below spec level, but was needed verify spec level testing could be performed. To verify the system wouldn't have these issues, the Raspberry Pi was mounted within the detection housing and the subsystem was placed in a freezer set to zero degrees for one hour. Images were taken every minute, and the percent difference was calculated via image subtraction. These results can be seen below in Figure 43.

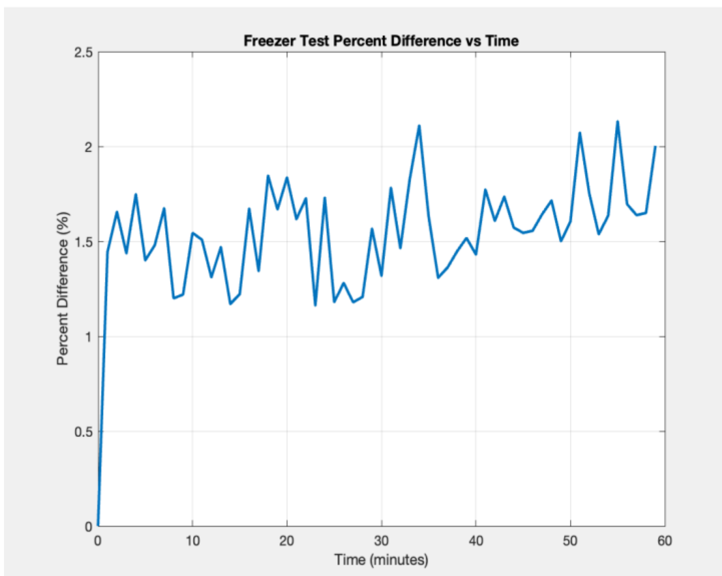


Figure 43: Angle Difference Results

From Figure 43, the system had a maximum percent difference of 2.2% and a mean of 1.53%. With error coming from subtle lighting changes and slight inconsistencies in the camera's focus, it was determined that this low temperature does not pose a threat to the integrity of the detection system's visibility. For extra verification and to make sure the dehumidification of a freezer didn't influence the results, a second test was performed, leaving the system outdoors overnight. Images were taken every five minutes for a run time of 10 hours, with an ambient temperature ranging from 26°F to 18°F. The results of this test can be seen below in Figure 44.

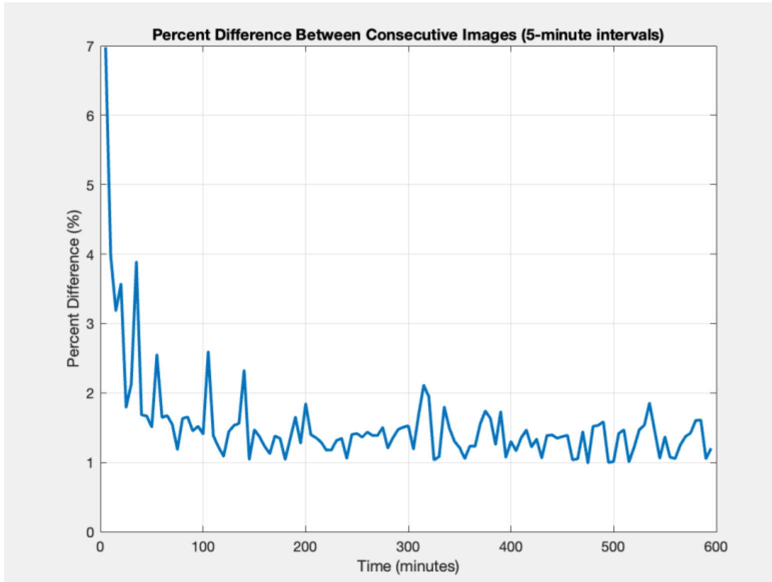


Figure 44: Test Results for Housing

The results were restructured to resemble the process used by the detection system, using difference between consecutive images. This provided a mean percent difference of 1.54%, and no visibility blocking conditions appeared. With purpose of this verification being a pass/fail for the cover of the housing unit meshing with the detection system, it is determined that the subsystem passed, and it was safe to move on to greater fabrication.

Moving forward, the housing and mounting systems became much more integrated, as all pieces moved towards the final system. The next verification performed was for Spec 2.1.2, where the system bust be able to operate in winds up to 20 mph. This testing wasn't performed to ensure operation, as that is a system level test, but instead to ensure that the housing and mounting systems can survive said winds so that actual verification could be performed later.

To perform this testing, the solar panels and both housings were mounted onto the PolyStakes with the components facing the desired directions (battery opposing the solar panel for better weight distribution). The equipped PolyStakes were then placed into a bucket of sand and the batteries were placed in their respective case. Sand was used as a substitute to snow due to the time of testing, where weather did not allow for the usage of snow. A level measuring device, in this case an iPhone app, was placed onto the system and an anemometer was held up next to it. A leaf blower was then started about 5 feet away and the power was increased until the anemometer read over 20 mph. This test was performed three times for each system, each from a different side, and the results can be seen below in Table 11. A pass for this test was determined to be an angle change of less than 5 degrees, as the PolyStakes are made of flexible polymer, which can safely bend to this deflection without yielding.

Table 11: Raw Test Results (Wind Speed and Angle Change)

Downhill Unit

Test Case	Max Wind Speed	Max Angle Change*	P/F
Back	25.6 mph	4.8°	Pass
Side	23.2 mph	1.7°	Pass
Front	24.8 mph	1.1°	Pass

Uphill Unit

Test Case	Max Wind Speed	Max Angle Change*	P/F
Back	20.2 mph	2.4°	Pass
Side	28.4 mph	0.4°	Pass
Front	27.8 mph	0.7°	Pass

As seen in the figure, the maximum angle change present was 4.8 degrees, with the greatest angle changes present with wind coming from the back. This was expected, as this is the side where the solar panels present the most drag. Some of the angle change also came from the base moving, which happens less when mounted deeper and in snow instead of sand. With both the uphill and downhill systems passing the verification, it was determined that winds up to spec level will not cause an issue with the housing and mounting.

3.5 *Subsystem 5: Mounting [Trevor Jordan]*

The mounting subsystem is responsible for securely anchoring the lighting and detection units into the snow while ensuring stability and ease of installation. This consists of a primary stake, which serves as the foundational support and is designed to resist environmental forces such as wind and impact from skiers. The system allows for efficient insertion and removal while minimizing the disruption to the snowpack.

3.5.1 *Mounting Design*

The mounting subsystem consists of a hollow polycarbonate stake reinforced with a square steel tube to provide the necessary structural support. The modifications to these components are shown in Figure 45 and Figure 46 with the dimensions and locations of each hole. The stake, commonly used in ski resorts, serves as the primary anchor, while the steel insert prevents bending or failure under the load of the batteries and solar panels mounted above. To securely attach the reinforcement to the stake, galvanized nuts and bolts were used, selected for their resistance to corrosion and harsh weather conditions. Through-holes were drilled into both the polycarbonate stake and the steel insert, allowing for a rigid mechanical connection that prevents movement.

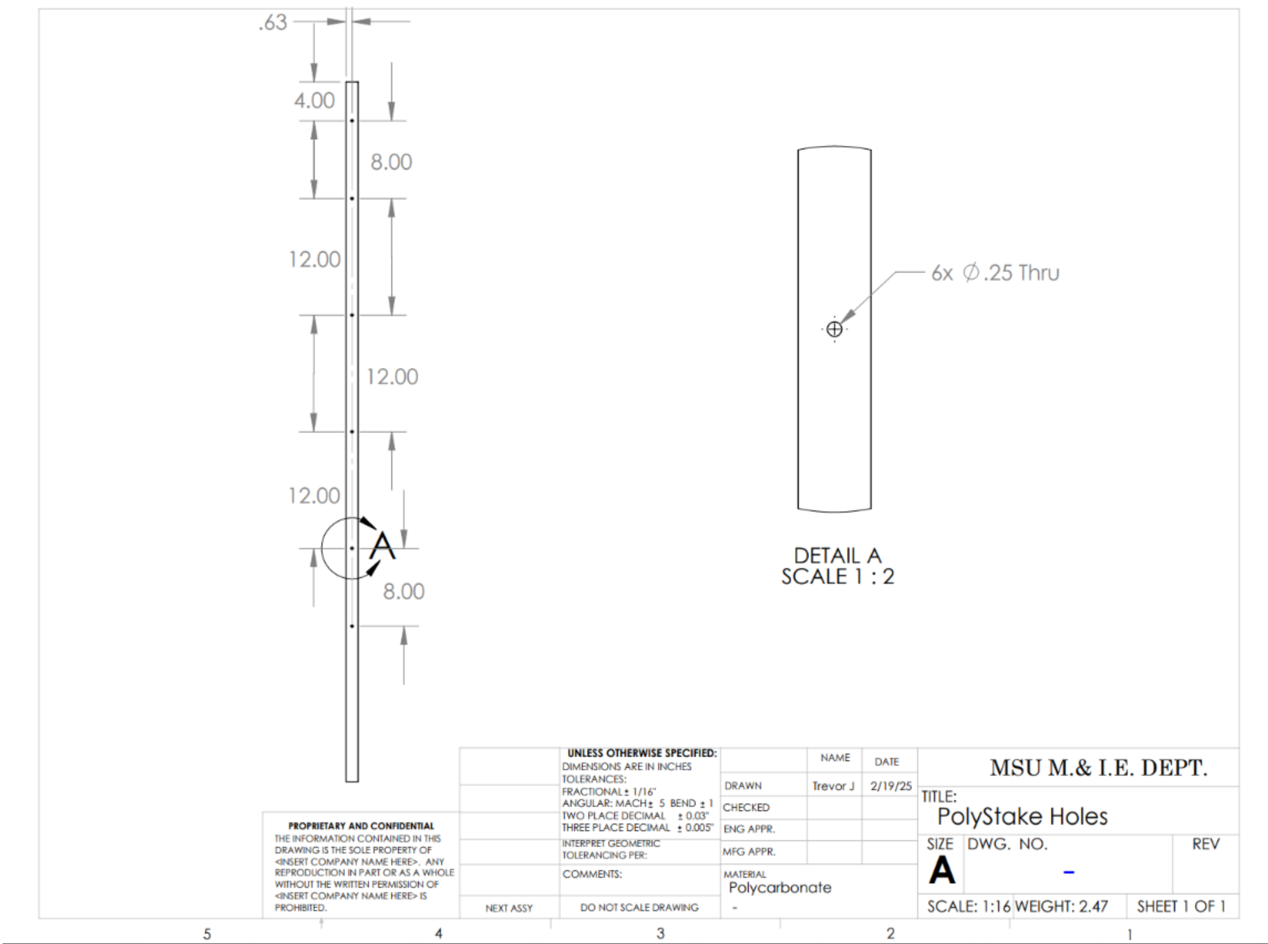


Figure 45: PolyStake Drawing

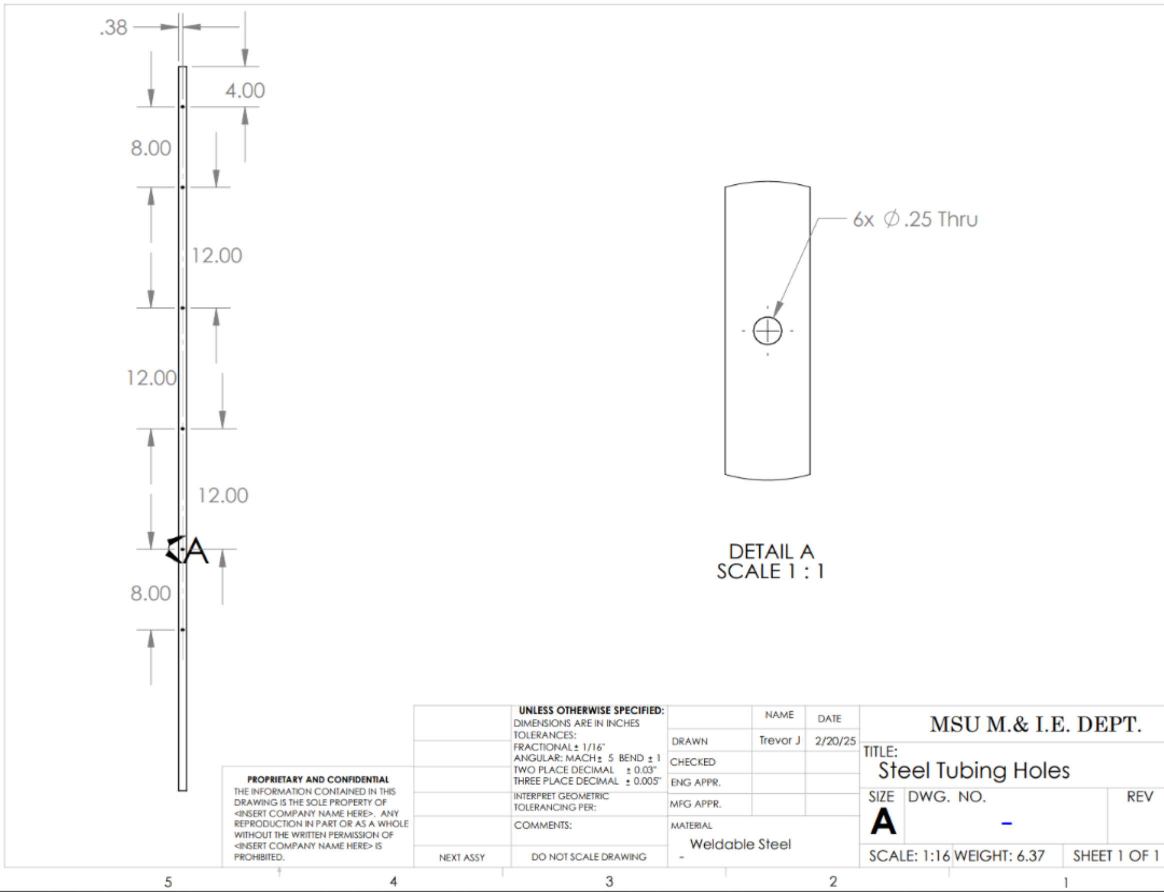


Figure 46: Steel Reinforcement Drawing

The mount for the solar panel shown in Figure 47 was designed to securely attach the panel to the stake while maintaining stability in harsh winter conditions. It was constructed from 6061 aluminum, a material selected for its lightweight properties, corrosion resistance, and structural strength. This ensured that the mount could endure prolonged exposure to moisture, cold temperatures, and high winds without compromising performance. The mount features 2 plates, one that attaches to the stake, and one that allows for the angle of the panel to be adjusted, ensuring the panel can be positioned at the optimal angle for sunlight exposure. This is achieved by loosening the screws and shifting the angle of the panel before tightening the bolts to lock the position in place.

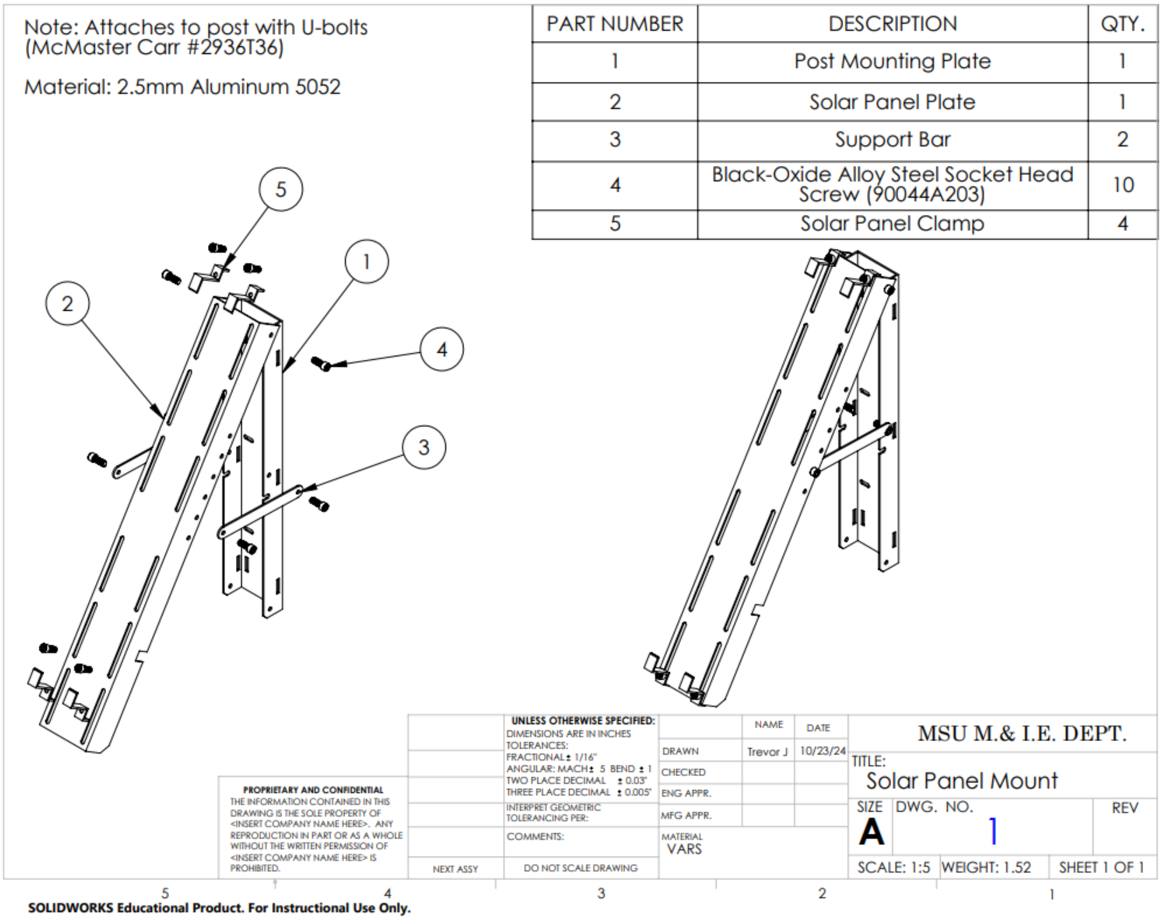


Figure 47: Solar Panel Mount Assembly Drawing

3.5.2 *Mounting Fabrication and Verification*

For testing spec 2.2.3, the testing setup required securing the stake in a stable, upright position to ensure accurate height measurements, with all three component housings mounted starting from the lowest position. The testing procedure confirmed the bottom-most position (0 feet) of each case using the measuring tape, followed by adjusting each case upwards in 6-inch increments with the U-bolts. At each increment, the actual height was measured and recorded. The stability of the stake was verified at each height, and the U-bolts were tightened securely to prevent slippage.

The data collected for each component was as follows:

- **Lighting Case:**

Target Height (ft)	Measured Height	Pass/Fail
0	0.00	Pass
0.5	0.51	Pass

Target Height (ft)	Measured Height	Pass/Fail
1	1.03	Pass
1.5	1.48	Pass
2	2.08	Pass
2.5	2.57	Pass
3	3.04	Pass
3.5	3.46	Pass
4	4.03	Pass
4.5	4.51	Pass
5	5.00	Pass

- **Battery Case:**

Target Height (ft)	Measured Height	Pass/Fail
0	0.02	Pass
0.5	0.52	Pass
1	1.02	Pass
1.5	1.53	Pass
2	2.05	Pass
2.5	2.56	Pass
3	3.08	Pass
3.5	3.53	Pass
4	4.09	Pass
4.5	4.53	Pass
5	4.98	Pass

- **Solar Mount:**

Target Height (ft)	Measured Height	Pass/Fail
0	0.06	Pass
0.5	0.53	Pass
1	1.03	Pass
1.5	1.54	Pass
2	2.09	Pass

Target Height (ft)	Measured Height	Pass/Fail
2.5	2.54	Pass
3	3.06	Pass
3.5	3.53	Pass
4	4.04	Pass
4.5	4.53	Pass
5	4.99	Pass

The pass criteria were that the deviation from the target height should not exceed ±0.15 inches. Based on these measurements, the system passed the specifications.

Data collected for spec 2.1.1 is presented in Figure 48. To verify this spec, which requires the smallest housing component to remain operational after exposure to sub-freezing temperatures, a controlled thermal test was conducted. The housing was placed inside a standard freezer set to 0°F, with a temperature and humidity sensor enclosed to monitor internal environmental conditions. Measurements were recorded at 10-minute intervals as the internal temperature dropped from room temperature (approximately 67°F) to 0°F over the course of 60 minutes, then remained stable for another hour to simulate extended cold exposure. Following the cold period, the housing was removed and allowed to return to room temperature, with humidity and temperature monitoring continuing for an additional 60 minutes. Throughout the test, internal relative humidity levels remained below the 90% threshold commonly associated with condensation risk. No evidence of moisture ingress, condensation, or material degradation was observed. These results confirm that the housing meets the requirements of Spec 2.1.1 and is capable of protecting internal components through rapid thermal cycling in cold-weather environments

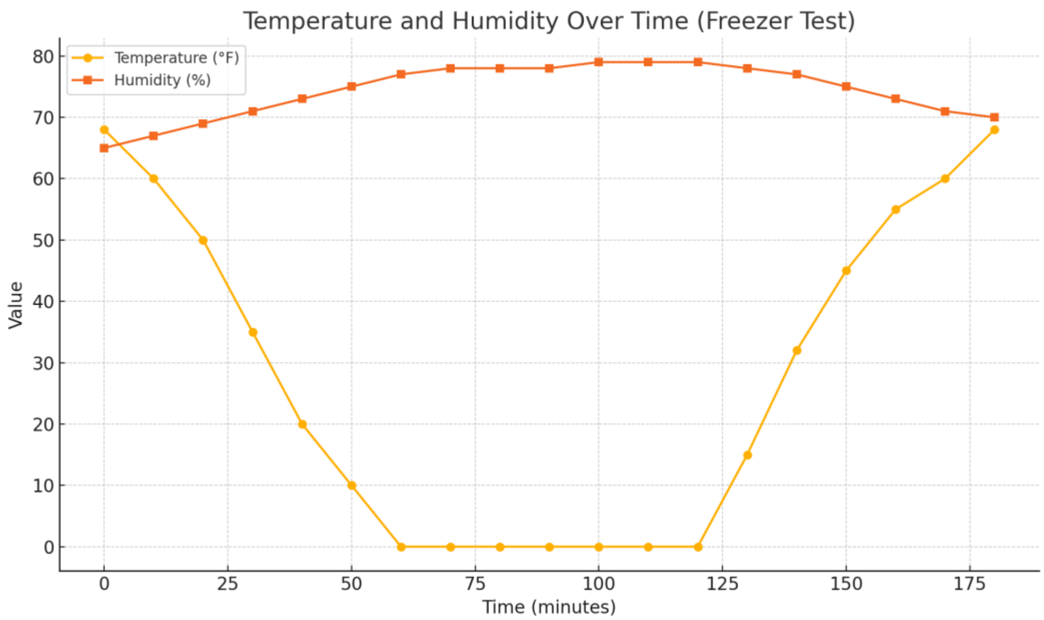


Figure 48: Spec 2.1.1 verification test results

4. System Fabrication and Verification

Now that the subsystems were fabricated, each subsystem needed to be integrated. Referencing Figure 49, each unit will be housed in its own housing unit. These housing units will be mounted on their own respective stake. Within each housing unit will be the detection system, communication system, and power systems. Each unit will have its own PCB. The downhill unit's PCB is a hat, sitting on top of the Raspberry Pi. This PCB holds traces that connect the LoRa module and the visible light camera mounts. The downhill power system connects directly to the Raspberry Pi, which distributes power accordingly. The uphill unit's PCB holds the MSP430, which uses traces to connect to the LoRa module and the signaling unit. The uphill power system connects directly to the PCB.

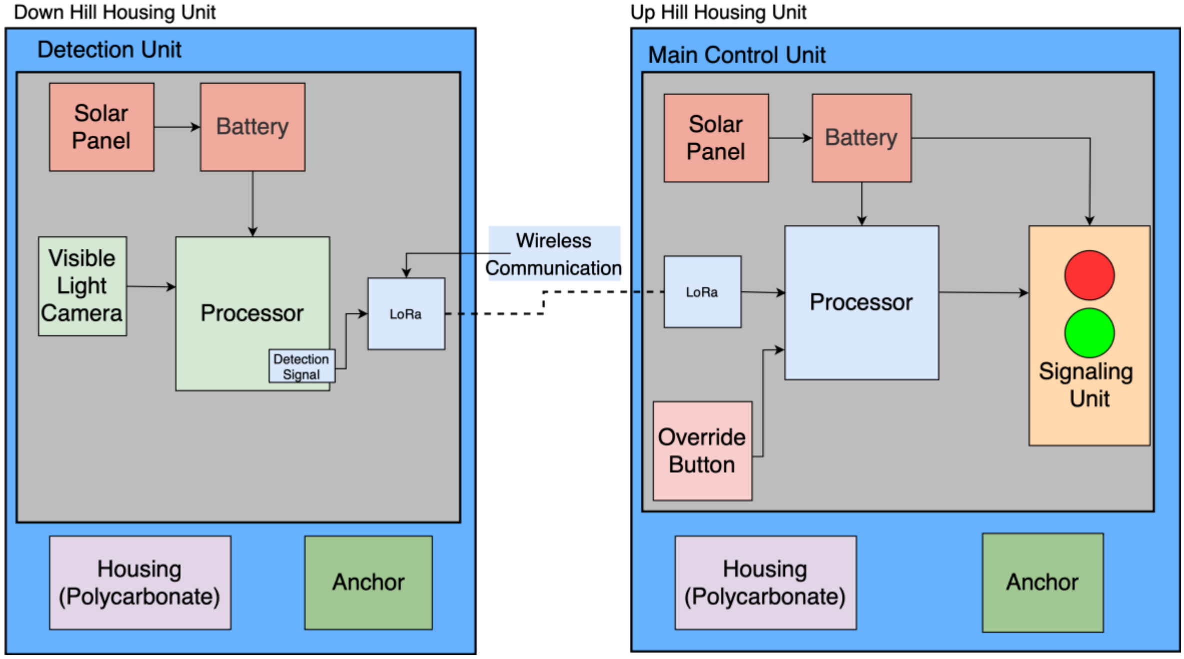


Figure 49: Conceptual block diagram

4.1 System Integration

The communication subsystem of the uphill unit interacts with the lighting system with a PCB (printed circuit board) shown in Figure 50. This PCB holds the MSP430 microcontroller, with traces connecting to the LoRa module, mounted with a 10-pin through hole header. The MSP430 connects to the lighting circuit, with traces connecting surface mount resistors to the base of the 2 transistors, one for the green light and one for the red light. The collector of both transistors is connected to 12V, with the emitter connected to the positive terminal of a 2-pin screw terminal. These screw terminals are where the wires of the lights connect.

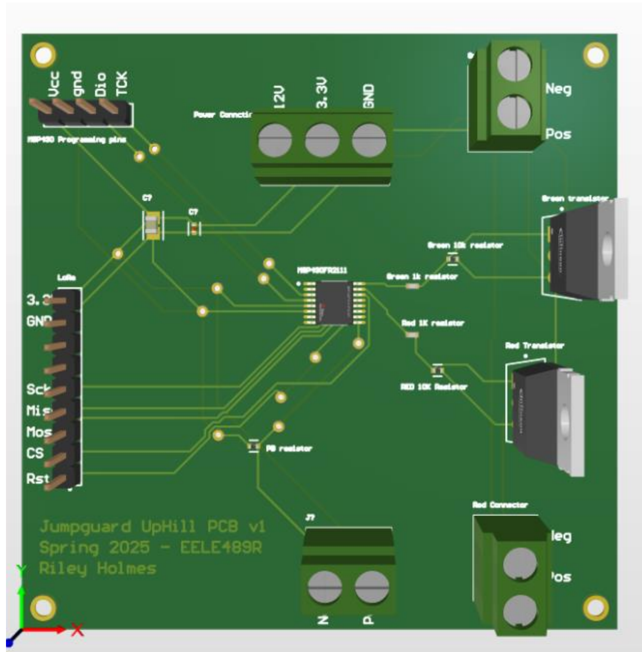


Figure 50: Uphill Unit PCB

Additionally, this PCB holds a 2-pin screw terminal to connect the push button to the PCB. To distribute power to the system, a 3-pin screw terminal is used to add 3.3V, 12V and ground to the PCB. To protect the sensitive electronics, the 3.3V line has a power stability circuit. Lastly, to allow programing of the MSP430, a 4-pin header is present and connected to the MSP430.

The lighting system connects to the uphill communication system through wires that run into screw terminals, Figure 51. The screw terminals connect to traces that run through a combination of resistors and transistors to the MSP430. The MSP430 is what controls what color of light illuminates.

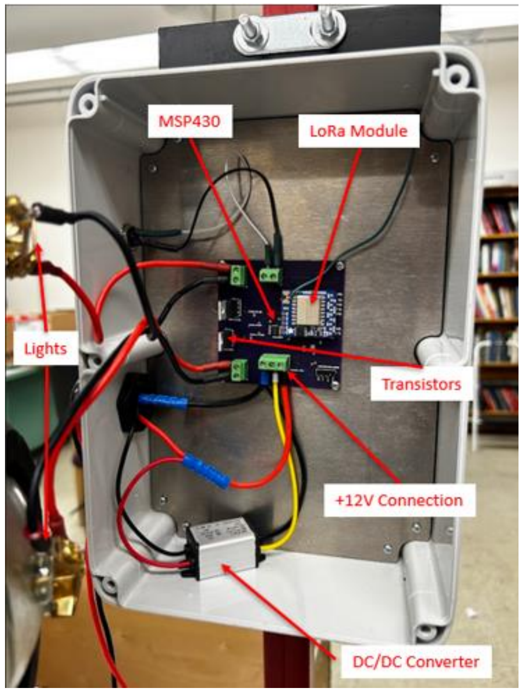


Figure 51: Lighting System and Communication PCB

The downhill detection subsystem integrates with the communication subsystem through a PCB as well, Figure 52. This PCB acts as a shield on top of the Raspberry Pi. The 40-pin header at the top of the PCB is where the connection to the Pi is made. From here the LoRa module SPI connections are made from the Pi. There is placement on the PCB for the LoRa module to mount directly. This allows for minimal wiring and mounting outside of the PCB shield. The Visible Light Camera for detection is also placed at the top of the PCB. This connection electronically is made through a CSI interface as seen in, Figure 8. The holes on the PCB allow for the camera to be mounted and also provide a simple mounting surface for all downhill electronics. There is placement on the PCB for a thermal camera if one were to need to be added in the future.

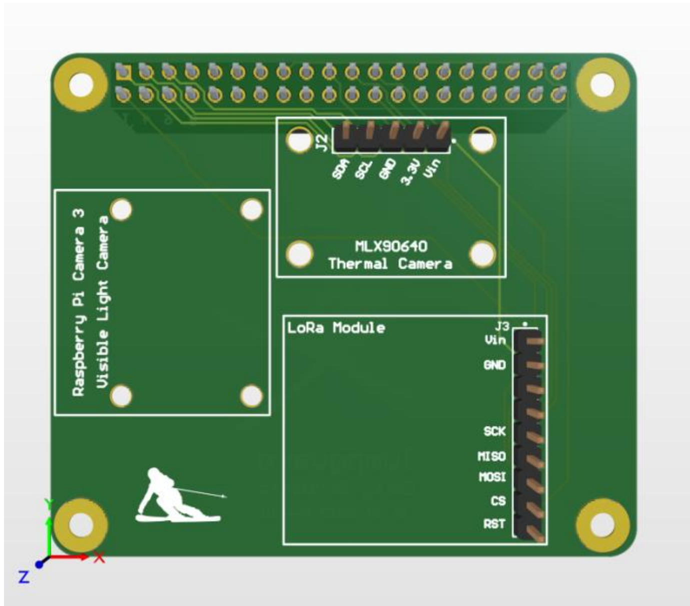


Figure 52: Downhill Unit PCB

The power connects to the downhill components through the Pi, Figure 53. There is one cable that powers the Pi, and all other power connections are down through the routing of GPIOs on the Pi. The DC/DC converter takes in the power from the solar panel and battery and shifts it down to the correct voltage and current for the Pi.

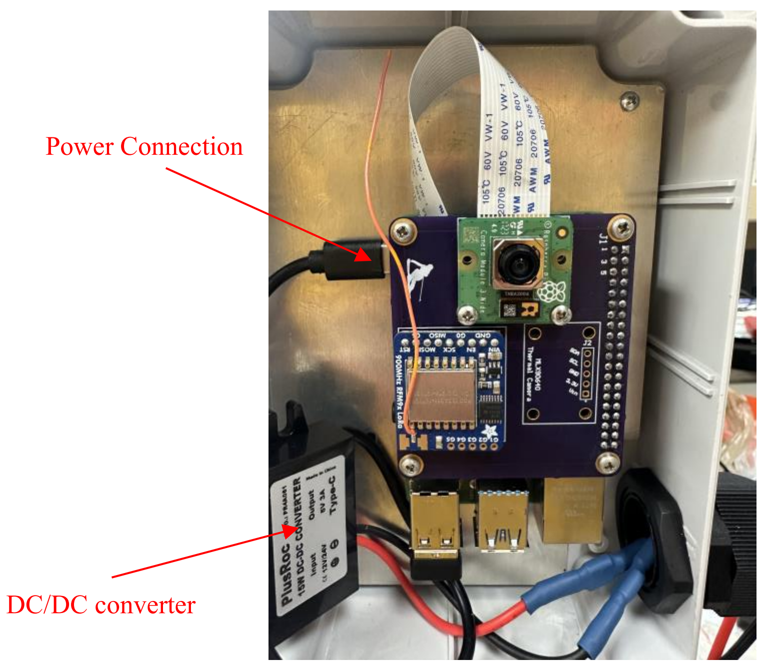


Figure 53: Downhill Power Connection to Detection and Communication

Figure 54 and Figure 55 show the technical drawing and 3D model of the mounts used to support the lights inside of their housings. The mounts, fabricated from PVC reducers, were cut at specific angles to fit securely within the internal structure of the case and position the lights to point straight out of the case. A hole at the base of each mount allows for clean and unobstructed wire routing to the internal power system. Red and green plexiglass filters were epoxied directly to the inside of the clear lid of the housing, aligning with the light positions. The mounts themselves were coated with matte black spray paint to absorb excess light and reduce internal glare. As shown in the drawing, these components work in tandem to create a lighting system that is not only mechanically and optically functional but also fully integrated with the form and function of the housing.

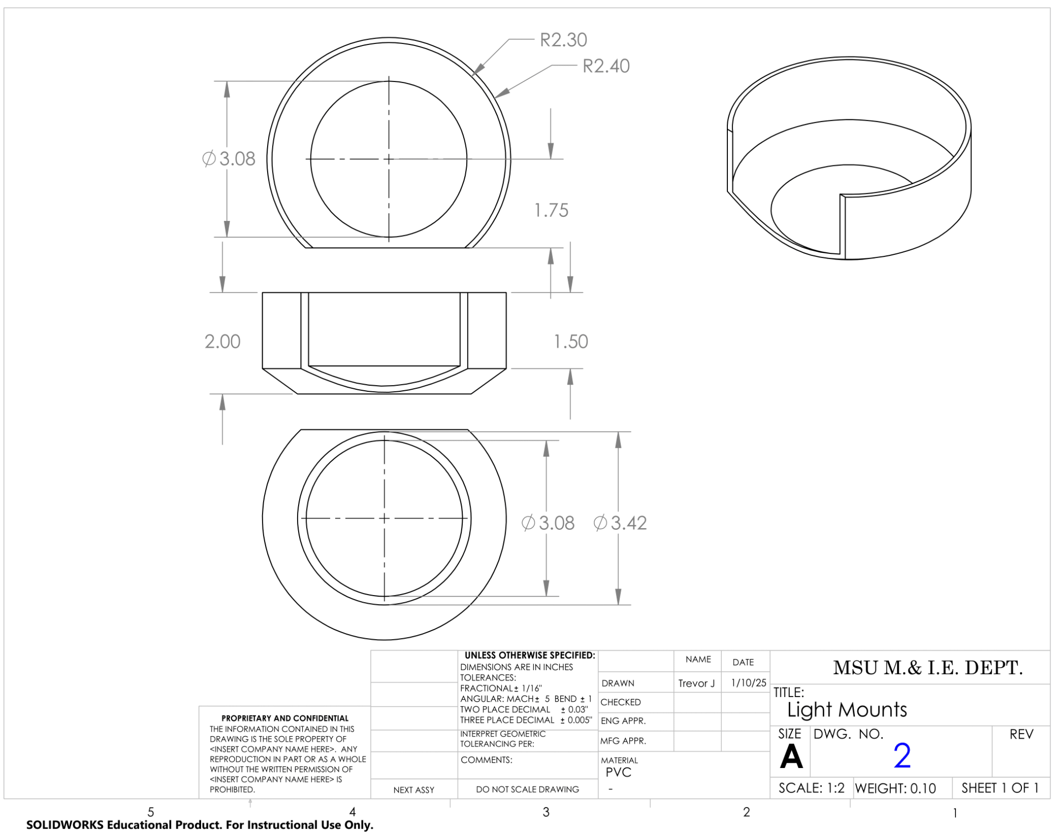


Figure 54: Light Mount Drawing

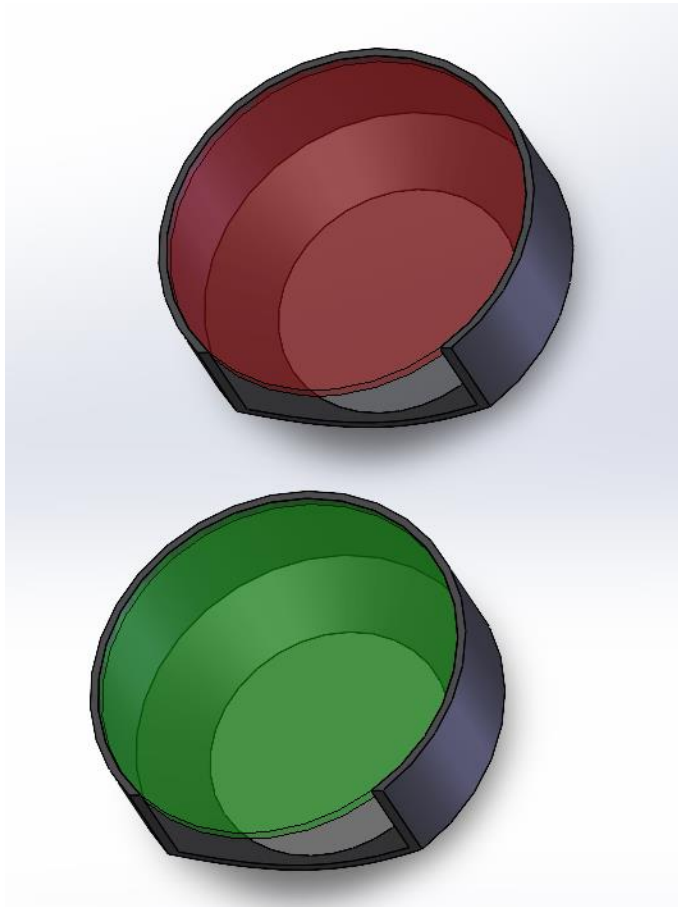


Figure 55: Light Mounts with Plexiglass Color Filter Model

The housing subsystem interacts with the detection, communication, and power components with individual housings, Figure 53 and Figure 56. Each unit has the charge controller and battery placed within the respective battery housing, and the detection and lighting systems were mounted within their own housings. All of the components were then either screwed or epoxied into place.

Figure 56: Uphill Power Components in Battery Housing

Finally, the mounting subsystem interacts with the housing and power subsystems by allowing all parts to be placed on the PolyStake, Figure 57. The solar panel is mounted to the solar panel mounting bracket, which is mounted on the PolyStake via the use of U-bolts. The housings are connected to their respective mounting brackets and are also mounted on the PolyStake with U-bolts.

Figure 57: PolyStake with All Components Mounted

4.2 Verification of Objective 1: This system will determine whether the detection area below a jump is clear, and then report the status to athletes uphill from the detection area

Verification of the communication subsystem at the system-level involved placing the two completed units 60 feet apart, as shown in Figure 58. Although the detection system wasn't working as intended, we were still able to change the detection results by placing a piece of paper over the camera before powering the system on. Once the system is powered on, removing the paper would set the detection signal, making the light turn red. Replacing the paper would unset the detection signal, making the light turn green. This test was ran 20 times over a 7-hour period, for 5 days.

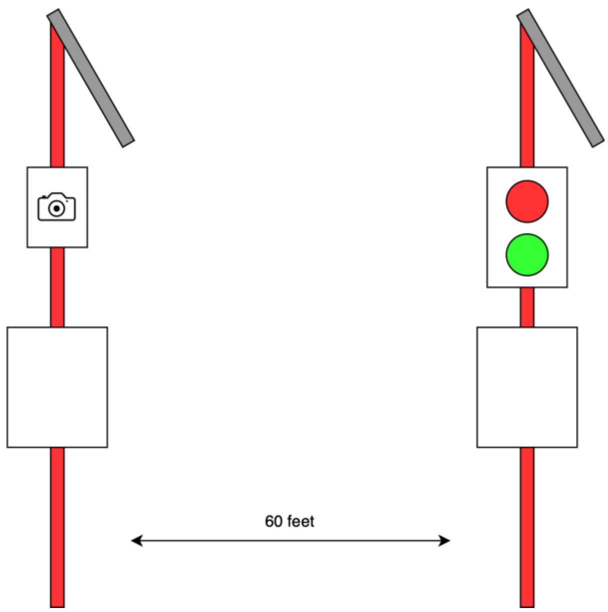


Figure 58: System Diagram

Table 12 shows a subset of the data collected, specifically the data from day one of testing, 4/6/25. Although this is just a subset of data, all data from all other days were identical. This test led to a communication rate of 100% and a dropout rate of 0%. In the table, a 0 indicates the lights didn't function as expected, whereas a 1 indicated the lights did function as expected, meaning when the paper was removed, the lights switched from green to red, and when the paper was replaces, the lights changed back to green.

Test #	Expected Detection Results	Actual Detection Results
1	1	1
2	1	1
3	1	1
4	1	1
5	1	1*
6	1	1
7	1	1
8	1	1*
9	1	1
10	1	1
11	1	1*
12	1	1
13	1	1
14	1	1
15	1	1
16	1	1*
17	1	1
18	1	1
19	1	1
20	1	1

Table 12: Communication Subsystem Results (Subset)

*Camera timed out, after a reboot, the system operated as expected

Due to difficulties with the detection subsystem in real world applications tests were conducted to determine the issues that occurred. These tests were meant to provide information for why the detection is not working in outdoor environments, but is working correctly in indoor, environmentally controlled, areas. In order to determine the cause of the detection subsystem's instability and false positives an analysis on difference values was conducted. This test is focused on validating the detection subsystem when no object is present and assessing whether environmental factors or system load contribute to false triggers or system failure.

For these set of tests the downhill unit, fully assembled except for the covering over the camera, are needed. Along with bungee cords to strap the unit to a post for stability. A separate display, HDMI cord, computer mouse, and keyboard to control the Raspberry Pi. Along with a measuring tape and cones to map out the detection area.

This test was conducted in three different environments, outside with full area available, inside with full area available, and inside with controlled lighting and smaller detection area. The outdoor tests had all environmental effects. This included wind, shadows, and light movements. The indoor test with full area had some of the complexity that the outdoor test had, but it did not have as much of the complexity. The area is larger and there is more to be differentiated from the correct things. The lab test had ideal conditions. The background remains as stable as possible throughout the test, and the distance of detection is much lower than the other tests. The camera is setup 2-3 ft away from the area that the participant can enter.

The setup was the same for the outdoor test and indoor test with the full testing area. The downhill unit was setup 60ft from the uphill unit, Figure 59. The downhill unit had a 30ftx30ft grid placed in front of it. The grid was 15ft away from the camera. The camera faced the square of orange cones. Additionally, the clear plastic in front of the detection subsystem was taken off in order to attach the display to the Raspberry Pi. This allowed the differences to be collected.

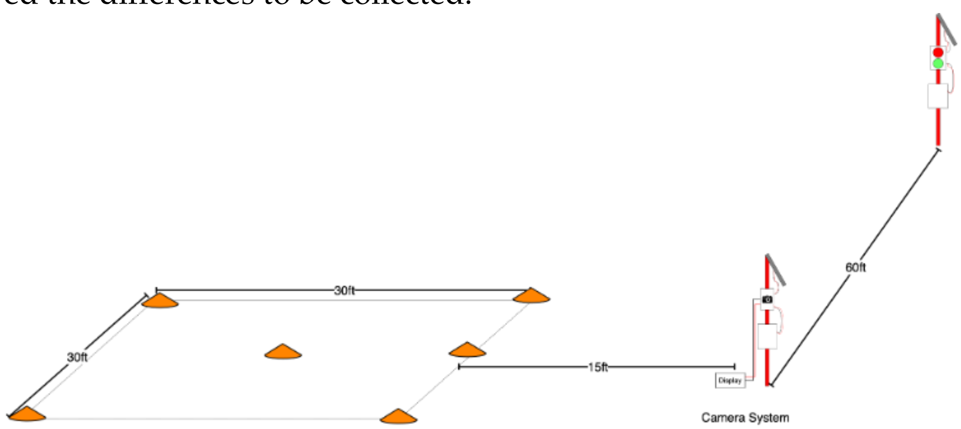


Figure 59: Testing Setup for Indoor and Outdoor Tests

For the test in the lab, the detection subsystem was connected to the display, and the camera faced the back wall of the senior design lab.

Testing Procedure:

1. Turn on the Raspberry Pi
2. Enter into the terminal and navigate to the software folder of the jumpguard repository
3. Once in there run the program that collects the differences between each frame
    i. Type this command in the terminal ***./testJump***
4. Allow the program to run for the set amount of time for the test
    i. Outdoor Test: 1 hour with participant, 1 hour with no obstructions
    ii. Indoor Test: 30 mins with participant, 30 mins with no obstructions

    iii. Lab Test: 10 mins with participant, 10 mins with no obstructions
5. For each test start with no participant in the detection area
6. After 2 minutes have the participant walk into the detection area, for the tests with the obstructions
7. Then have the participant stay in the area for:
    i. Outdoor Test: Walk around the square for approximately 5 minutes
    ii. Indoor Test: Walk around the area for approximately 5 minutes
    iii. Lab Test: Stand in front of the camera for 2-3 image captures
8. Then have the participant leave the detection area
9. Repeat steps 5-8 for the entirety of the time, laid out in step 4, for the test with obstructions
10. For the test without obstructions have nothing enter the area

Results:

The results of the outdoor test, Figure 60, shows that it is difficult to determine when there is a participant present and when there is not. There are significant differences that occur randomly between frames, without any obstruction by a person. The outdoor, real world, scenario contributes a significant amount of noise to the background of the processing. There are random, and often, jumps to high differences when there are no people present.

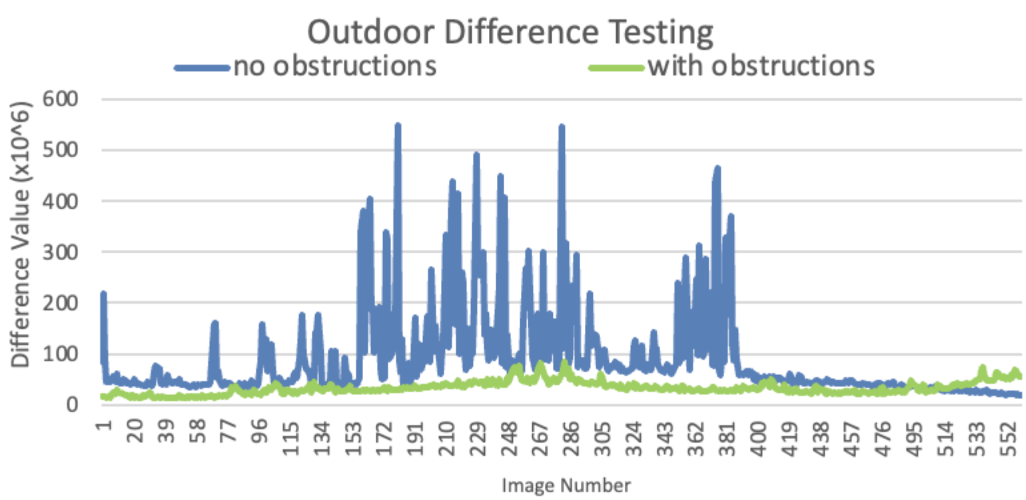


Figure 60: Data Results of Outdoor Test

The indoor testing provided more stability in the jumps in differences, Figure 61. It was more evident when there was a participant entering the area. However, there was still some subtle jumps that were caused by the environmental shifts. This test provided a clear connection between the shifts in the environment and the changes seen by the camera. There is a significant shift in the differences where there were no obstructions at the end. This is due to the lights in the area turning off. In order to preserve no obstructions, there was no movement to turn them back on.

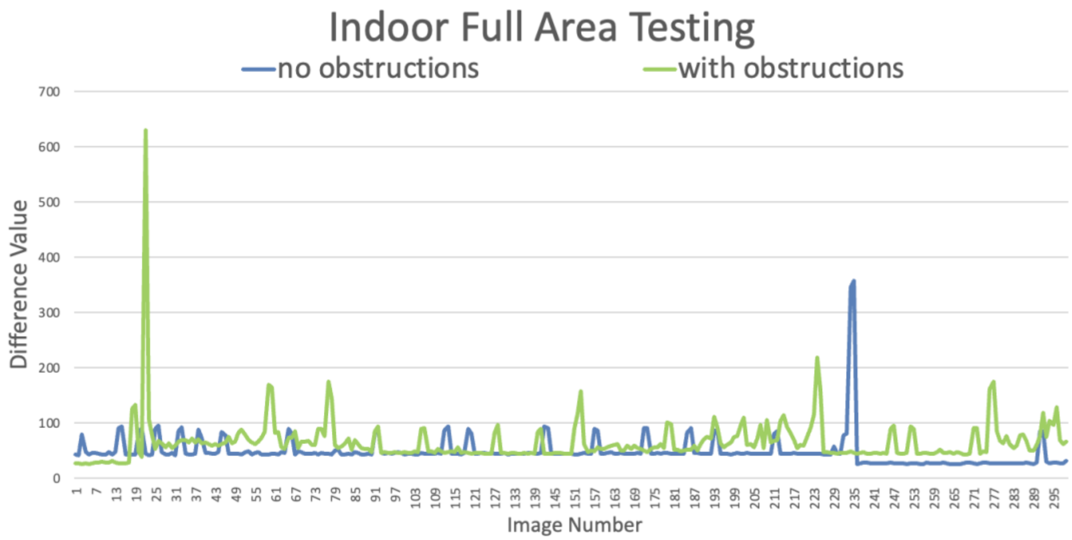


Figure 61: Data Results of Indoor Test

In the lab testing, under ideal conditions there was consistent accuracy, Figure 62. In the lab conditions the accuracy was found to be 100%. This was using a much smaller area. The distance between the camera and the obstruction is much closer than in the other tests. It is evident in this test the points in which a person enters the detection area. This test proved the algorithmic logic for the project, and that more filtered results could prove to better evaluate the differences. If there were more ways that the system was checking for a result, then the accuracy could go up in real world situations.

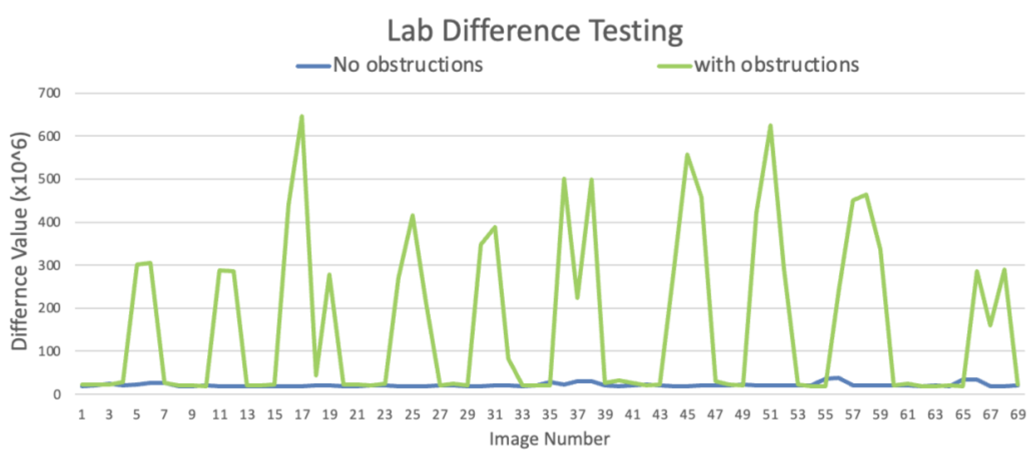


Figure 62: Data Results of Lab Test

This test provided vital data to understanding the difference measurements in real world scenarios. It provided a proof of concept for the sponsors to base future work off of. The thresholding was proven to work, in a controlled environment. When the system was placed into a real-world scenario the logic calculations were still right but the complex changes that would happen cause the system to falsely trigger a positive detection. Looking forward it would be important to add a thermal camera that would be able to cut past all the noise and focus on the heat signatures, and region filtering. These additions would provide more robustness in the system.

4.3 *Verification of Objective 2: The system must operate in inclement weather throughout the months of December through April*

Table 13 outlines the data collected from 1 day of outdoor testing on the most extreme day of conditions. To verify the system's durability under winter conditions as outlined in Objective 2, the same outdoor test setup was used as communication testing (Section 4.2) to assess environmental durability. Specifically, the ability to protect internal components and maintain stability when exposed to precipitation and wind. The outdoor test spanned a week long period during early April where the full system was setup from 9am to 4pm. Throughout each day, 20 functionality tests were conducted at randomly selected times. At each time, the wind speed, temperature, and overall weather conditions were recorded. The weather conditions were taken from the Montana State ORSL weather station which operates full time giving accurate local weather data.

	Expected Detection Signals	Actual Detection Signals	Time	Weather	Light Visible?	Wind	Temperature
Test 1:	1	1	9:00 AM	Cloudy	Y	*	*
Test 2:	1	1	9:17 AM	Cloudy	Y	*	*
Test 3:	1	1	9:40 AM	Cloudy	Y	*	*
Test 4:	1	1*	10:20 AM	Cloudy/breeze	Y	1.54 mph	48.0 F
Test 5:	1	1	10:30 AM	Cloudy/breeze	Y	2.09 mph	47.8 F

Test 6:	1	1	10:50 AM	Soft hail	Y	1.21 mph	46.8 F
Test 7:	1	1	11:05 AM	Light hail	Y	1.13 mph	47 F
Test 8:	1	1*	11:28 AM	Cloudy	Y	0.5 mph	48 F
Test 9:	1	1	11:35 AM	Cloudy/slight breeze	Y	1.1 mph	48 F
Test 10:	1	1	11:54 AM	Cloudy	Y	2.2 mph	48 F
Test 11:	1	1	12:10 PM	Cloudy	Y	2.6 mph	49 F
Test 12:	1	1*	12:33 PM	Partly sunny	Y	4.1 mph	51 F
Test 13:	1	1	12:50 PM	Partly sunny and wind gusts	Y	3.0	51 F
Test 14:	1	1	1:00 PM	Partly cloudy/breeze	Y	3.3 mph	52 F
Test 15:	1	1*	1:30 PM	Mostly sunny	Y	1.5 mph	53 F
Test 16:	1	1	2:00 PM	Mostly sunny/ gusty winds	Y	5.2 mph	54 F
Test 17:	1	1*	2:30 PM	Sunny	Y	1.8 mph	56 F
Test 18:	1	1	3:15 PM	Sunny/Cloudy	Y	23 mph	54 F
Test 19:	1	1	3:30 PM	Sunny/Cloudy	Y	24 - 40 mph	54 F
Test 20:	1	1	3:40 PM	Sunny	Y	10 mph	52 F

Table 13: Housing and Mounting Subsystem Results (Subset)

*Temperature and wind data not collected, can be assumed to be <5mph winds and between 40°F and 50°F during these times

The fully assembled JumpGuard system, including the housings, electronics, solar panels and mounts, and stake were mounted upright using two five gallon buckets filled with sand. These buckets acted as a substitute for snow, providing a stable but temporary base for the system throughout the test period.

Over the course of this week-long test, the system was exposed to a wide range of weather conditions, including overcast skies, light and soft hail, intermittent sunshine, and sustained wind. The system successfully withstood wind speeds above 20 mph, verifying spec 2.1.2.

While req 2.1 was somewhat verified while performing the week-long objective testing, enough weather fluctuation was not present. More testing was done to gather additional data needed to confidently pass the req and verify the system for Objective 2. To gather this data, the following procedure was followed:

Test Procedure

1. Line housings internally with paper towels, focusing on seams and holes for wires/buttons

2. Spray the housing at a 45° angle from:

  - Front

  - Left

  - Right

  - Top

  (~1 minute per angle, continuous spray)

3. After 4 minutes, turn off water, dry the outside, and open housing.

4. Inspect internal surfaces and absorbent paper

5. Record observations and test electronics

Table 14 shows the data collected from the testing. While no water was present in any of the housings, the signaling and detection housings both presented with slightly damp internal paper towels, specifically around the wire glands. The leak being present in the signaling and detection housings only does make some sense, as the wire glands in the battery housing have all four wire holes running wires, whereas these glands only have two. While the electronics remained functional, water ingress will likely lead to eventual failure, and the requirement had to be failed. This test provided valuable information on where fixes need to be made to confidently have the system pass objective 2.

Table 14: Requirement 2.1 Test Results

Housing	Water Present?	Absorbent paper damp?	Leak Location?	Electronics Functional?
Uphill Signaling	N	Y	Wire Gland	Yes
Uphill Battery	N	N	N/A	Yes
Downhill Detection	N	Y	Wire Gland	Yes
Downhill Battery	N	N	N/A	Yes

Pass/Fail Criteria
PASS: No visible internal water, dry paper/sensors, electronics working normally.

FAIL: Any sign of internal water, malfunctioning components, or wet absorbent indicators.

Furthermore, a slight oversight was made in the assembly of the system prior to this testing, where the rubber stoppers meant to plug the excess holes in the wire glands were not present. This likely is the cause of failure for the system level test and will need to be redone with them in to accurately assess the verification of objective 2.

4.4 Verification of Objective 3: The system will operate on a standalone power system to avoid running power lines to the system which could create unnecessary hazards

System level verification for the power system consisted of setting up the entire JumpGuard system for multiple seven-hour days, using both solar energy and backup power to operate the system. Figure 63, the uphill unit in the foreground, and downhill unit being set up in the background. To properly set up the system, all charge controller connections (Figure 20) were verified, the PolyStake was placed in sand, and then secured to plywood. The solar panels in Figure 63 are shown to be connected by MC4 connectors. On days when backup power was tested, the MC4 connectors were disconnected.

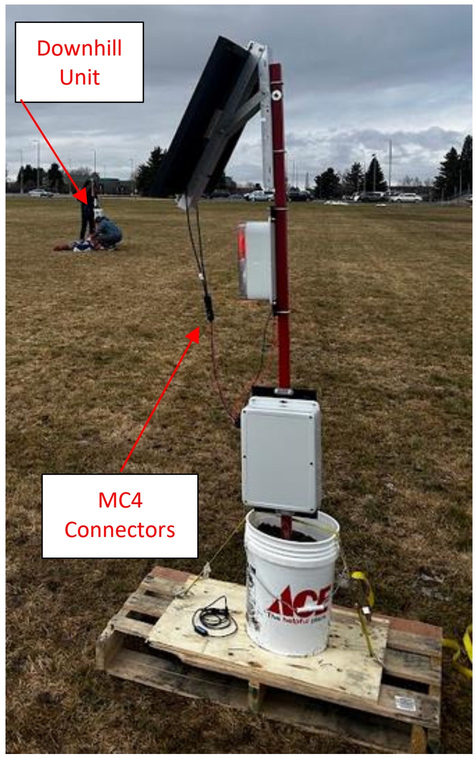


Figure 63: Full JumpGuard System Being Setup

Based on the requirements and specifications defined for Obj 3), the power system was tested to verify that the entire JumpGuard system could operate reliably under various conditions. High level testing consisted of ensuring the system could operate in various weather conditions, proven by testing the entire system using backup power for at least seven continuous hours. The power system is also required to recharge both with primary and secondary sources, this was proven by recharging the p batteries with both solar energy and an external battery charger in sufficient time. The entire JumpGuard system was operated and tested over the dates 4/5/2025 through 4/11/2025.

Over the seven-day span, data was collected by using the Victron Connect app. Figure 64 is an example of how the charge controller power data is presented in the Victron Connect app after a few days of operating the system. Columns are labeled to indicate what day the bar chart represents, and each respective day's power statistics. Each bar is broken up into three colors: white, light blue, and dark blue. White represents when the battery is in the absorption state, light blue is when it is in the bulk state, and dark blue is when it is in the float state. Highlighted below the bar chart, yield and consumption; these represent how much solar energy was generated, and how much energy the battery consumed.

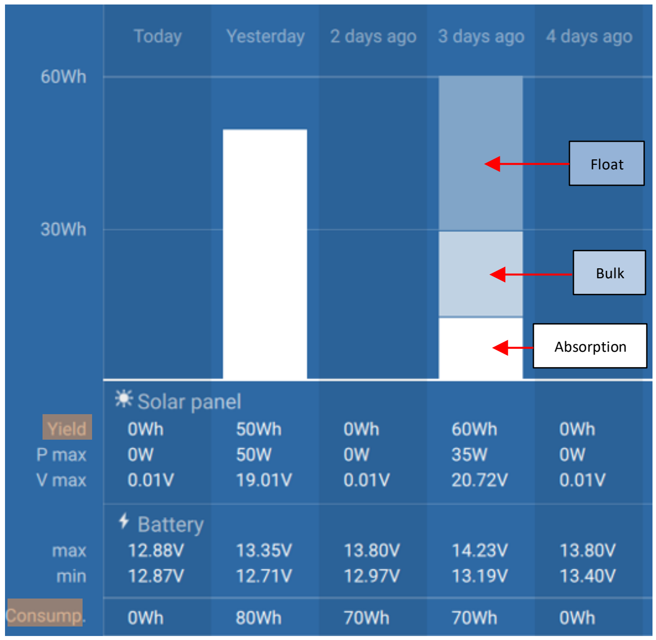


Figure 64: Example Data from Victron Connect App

Data was collected over a total of seven days, all data from the Victron Connect app was then translated to excel spreadsheets through a feature in the Victron Connect app, Table 15 shows the results of one week of data collection for the uphill unit. The table's columns are defined by date, yield, minimum battery voltage, and maximum battery voltage.

Table 15: Uphill Power System Testing Results

Date	Yield(Wh)	Consumption(Wh)	Min. battery voltage(V)	Max. battery voltage(V)
4/11/2025	0	80	12.87	13.43
4/10/2025	160	70	13.15	14.21
4/9/2025	0	80	13.12	13.27
4/8/2025	50	80	12.71	13.35
4/6/2025	60	70	13.19	14.23
4/7/2025	0	70	12.97	13.8
4/5/2025	60	70	13.4	13.8

The power system continuously operated for seven hours each testing day, operating on backup power 4/7/2025, 4/9/2025, and 4/11/2025. On days not run with backup power, the solar panels were utilized and solar energy was generated. To fully verify that all requirements and specifications were met for the uphill system, the data for 4/9/2025 through 4/11/2025 will be investigated, Table 16. Yield is zero on 4/9/2025 and 4/11/2015, these were days when the system operated using backup power. On 4/10/2025 the system operated with the solar panels connected. To verify enough solar energy was generated to operate the system and recharge the backup battery, the yield had to be high enough to surpass the consumption on 4/10/2025.

Table 16: Testing Data April 9th Through 11th

Date	Yield(Wh)	Consumption(Wh)	Min. battery voltage(V)	Max. battery voltage(V)
4/11/2025	0	80	12.87	13.43
4/10/2025	160	70	13.15	14.21
4/9/2025	0	80	13.12	13.27

Because the system could continuously operate on backup power the day before and prior to 4/10/2025, it is verified that the system can recharge the batteries enough for a seven-hour operational day. To fully verify the objective, it had to be proven that the batteries could recharge in under three and a half hours of peak sunlight. Figure 65, solar irradiance data from the Montana State weather station [20]. Boxes were used to estimate the amount of peak sun that the system received on 4/10/2025.

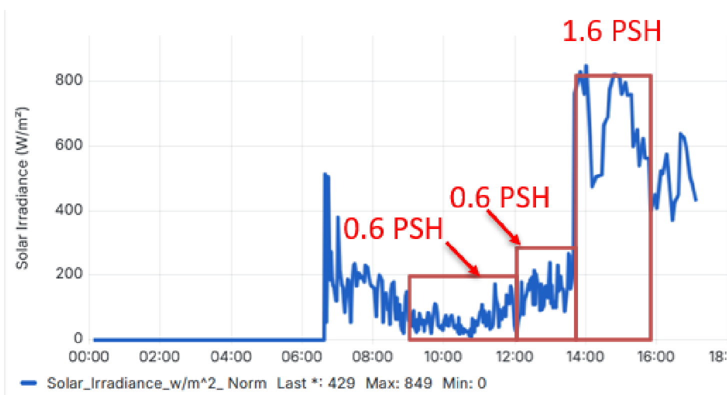


Figure 65: Solar Irradiance Data for 04/10/2025

Adding the area of each box gives a total of 2.8 hours of peak sun. Because 2.8 hours of peak sun is less than the maximum 3.5 hours outlined in the requirements document, the objective is verified. Table 17, the power results for the days 4/5/2025 through 4/11/2025. The columns follow the same format, displaying the date, solar yield, and consumption. The downhill unit, like the uphill unit, was able to pass all requirements and specifications under Obj 3).

Table 17: Downhill Power System Testing Results

Date	Yield(Wh)	Consumption(Wh)	Min. battery voltage(V)	Max. battery voltage(V)
4/11/2025	0	40	13.24	13.39
4/10/2025	70	40	13.25	14.22
4/9/2025	0	30	13.24	13.39
4/8/2025	40	30	13.26	14.22
4/7/2025	50	30	13.28	13.49
4/6/2025	0	30	13.25	13.31
4/5/2025	20	30	13.25	14.52

Both uphill and downhill standalone power systems were able to operate reliably through various weather conditions, operate off solar energy and backup power, and recharge through primary and secondary sources. Power lines were never used to supply power to the system while operating, avoiding unnecessary hazards, and thus verifying Obj 3).

4.5 Complete Verification Summary

Table 18: Performance Verification Summary
{JumpGuard - Complete System}

Num	Name	Test description	Result	Date
1	Objective 1	System was ran for a week long outdoor test	System did not properly detect a person in the area	4/5 - 4/11
	Reuirement 1.1	System was tested in a controlled indoor test and outdoor test	In controlled smaller environments the system can detect a clear detection	4/09-4/12
	Requirement 1.2	The entire system was step up 60 feet apart. A sheet of paper over the camera was used to simulate the detection signal	The lights changed as expected, everytime	4/06-4/10/25
1.2.1	Specification 1.2.1	With the LoRa modules connected, the Raspberry pi sent a signal every 480 ms for 1 hour. The latency was measured using an AD2	Every signal's latency is ≤0.5s	3/2/25
	Specification 1.2.2	The entire system was step up 60 feet apart. A sheet of paper over the camera was used to simulate the detection signal	The lights changed as expected, everytime	4/06-4/10/25
	Specification 1.2.3	The entire system was step up 60 feet apart. A sheet of paper over the camera was used to simulate the detection signal	The system was able to communicate over 60 feet and the ligths changed as expected	4/06-4/10/25
	Specification 1.3.3	Uses spec 1.2.1 test as the timing for this spec is included in spec 1.2.1	Latency is ≤0.5s	3/2/25
	Specification 1.3.4	Thorughout a 7 hour period, the push button was pushed a total of 10 times	The lights changed as expected	4/7/25
2	Objective 2	System ran for seven days and weather data was collected	System withstood a week of normal operating conditions	4/5 - 4/11
	Requirement 2.1	System was sprayed to simualte heavy rain and weather	Slight water ingress through wire glands	4/13/25
	Specification 2.1.1	Housings were placed in a freezer with a temperature and humidity sensor	Humidity never crossed 80% while at 0F	3/10/25
	Specification 2.1.2	System was placed outdoors in a bucket of sand over a week long test	System never fell out of its mounting spot	4/5 - 4/11
2.1	Requirement 2.2	System was observed over a week of outdoor testing	Signal was always visible	4/5 - 4/11
	Specification 2.2.1	System was set up up to 200ft apart	Signal was visible from 200ft	4/9/25
	Specification 2.2.2	Lights were measured with a Luxmeter throught the color filters	Both lights provided over 1000 Lumens	2/2/25
	Specification 2.2.3	Housings were moved along the Polystake up to 5ft	Housings move individially 5ft, whole system does not	4/12/25

3	Objective 3	System ran for seven days, power data was collected	system operated continuously each day	4/5 - 4/11
3.1	Requirement 3.1	System was run in varying winter conditions	system never lost power	4/5 - 4/11
3.1.1	Specification 3.1.1	System ran continuously 7 hours	system never lost power	4/5 - 4/11
3.1.2	Specification 3.1.2	System operated on backup power on multiple days	System ran continuously on backup power	4/5 - 4/11
3.2	Requirement 3.2	Solar energy and an external battery charger were both used to recharge the system	External charger and solar panels both prooperly charged system	4/5 - 4/11
3.2.1	Specification 3.2.1	Sun hours were tracked while solar panel powered system	System operated and recharged vith 2.8 PSH	4/5 - 4/11
3.2.2	Specification 3.2.2	Batteries were charged after a day of testing backup power	Charged in under 8 hours	4/5 - 4/1

5. Conclusions

5.1 Summary of Project Results

The goal of the JumpGuard system is to improve safety on terrain park jumps. JumpGuard is designed to detect when an athlete is present in the landing area of a jump and signal to uphill athletes when it is safe to proceed. The system uses image subtraction to detect when an object enters the camera's field of view, and the results are processed and transmitted to the signaling unit via LoRa communication. Once the signal is received, the signaling unit displays either a red or green light based on the status of the landing zone.

Although the finalized JumpGuard system did not fully pass every system-level objective, it successfully demonstrated a strong proof-of-concept. JumpGuard could successfully detect objects in a controlled environment, proving that the algorithm logic, adaptive thresholding, and thermal performance functioned correctly. Detection results were reliably transmitted between both units, achieving a 100% communication rate, and 0% dropout rate. The signaling unit accurately responded to incoming data by changing the light colors as intended.

The mechanical housings provided sufficient weather resistance under the environmental conditions available during testing. The system was able to remain stable when properly staked into the ground and could obtain a full five feet of adjustability if a longer PolyStake is used.

Each unit operated on an independent, solar-powered energy system consisting of a 50W panel, LiFePO4 battery, and MPPT charge controller. The power subsystem was tested over multiple-day cycles and reliably supported over 7 hours of continuous operation on a full charge. Power systems recharged effectively under available daylight conditions and required no external power source—fulfilling the requirement for standalone, off-grid operation in a mountainous terrain park environment. [1]

5.2 Future Work

Power:

Although all requirements related to power successfully passed, future iterations could include changes to the components selected. When designing the downhill power system, the power consumption of the Raspberry Pi was unknown. Because it was unknown how much power the Raspberry Pi would consume, the calculations for the downhill system were done assuming that the Raspberry Pi was always operating at full power (15 W). Using the full power assumption, the downhill battery had to be 30Ah in capacity to meet the backup power requirements. After system level testing was completed, it was found that it only takes roughly 2-4W to operate the Raspberry Pi. Because of the actual power consumption being far less than what was calculated, a smaller battery and solar panel could be used to reduce cost and weight of the system. If more days of backup power are desired, or future methods of processing consume larger amounts of power, larger batteries and solar panels could be implemented. The power system has been designed in such a way that allows flexibility to change components based on requirements like: Backup power needed, recharge time, solar efficiency, amount of sun in a region, and battery lifetime.

Detection:

Although not all detection goals were met in the field, the detection subsystem was proved to be effective in stable, low-noise, environments. When conditions were ideal the algorithmic logic was accurate to 100% and remained reliable. However, once environmental noise and other complexities were added in the system became unstable and was unable to perform effectively. In order to mitigate issues with detection in the future and allow for execution into real world scenarios, a couple of options of tools to implement would be, region filtering, and a thermal camera.

Region filtering would help to reduce the strain on the detection due to the noise in the background of the camera's view. This adjustment to the logic would include, isolating clumps of differences, instead of scanning the entire image for differences. This would provide more precise object finding ability. The algorithm would now look for large areas of differences instead of having the possibility of the entire image consisting of small pixel differences spread out throughout. If there was a clump of a certain size, then the algorithm would determine if it was an athlete in the area or not.

The addition of this tool would reduce the small noise additions that come with slight changes in camera focus, or other camera settings that adjust every image.

The addition of a thermal camera would eliminate the noise due to environmental shifts. This camera would not pick up on subtle shifts in the light, or the grass blowing in the wind. This camera would only be able to see the heat signatures of the athletes once in the area. Execution of a thermal camera would provide the detection algorithm with more information about what is in the frame. Allowing the algorithm to determine the objects in the detection area based on the thermal signatures allows for many shifts in the sun, and snow. Environmental concerns would no longer need to be acknowledged by the processing of the thermal images. However, there would need to be research and testing done to determine how layers of clothing affect the ability of the thermal camera to register athletes.

Another issue that was found during the system level testing was the camera had an issue of timing out after about an hour of use. A likely cause of this was determined to be the CPU temperature and processing time to be high for prolonged periods of time, Figure 66. As can be seen the CPU temperature peaks at about 58ºC. This is a sample of the testing data that was collected during the power and communication tests. The manufacturers of Raspberry Pi, recommend that the computer chip does not go higher than 80ºC, as this will cause damage to the entire computer board. However, they also recommend that during normal operations the temperature stay below 60ºC. It is gathered that prolonged period at these temperatures and increased processing time, contributes and causes the camera timeouts of the subsystem.

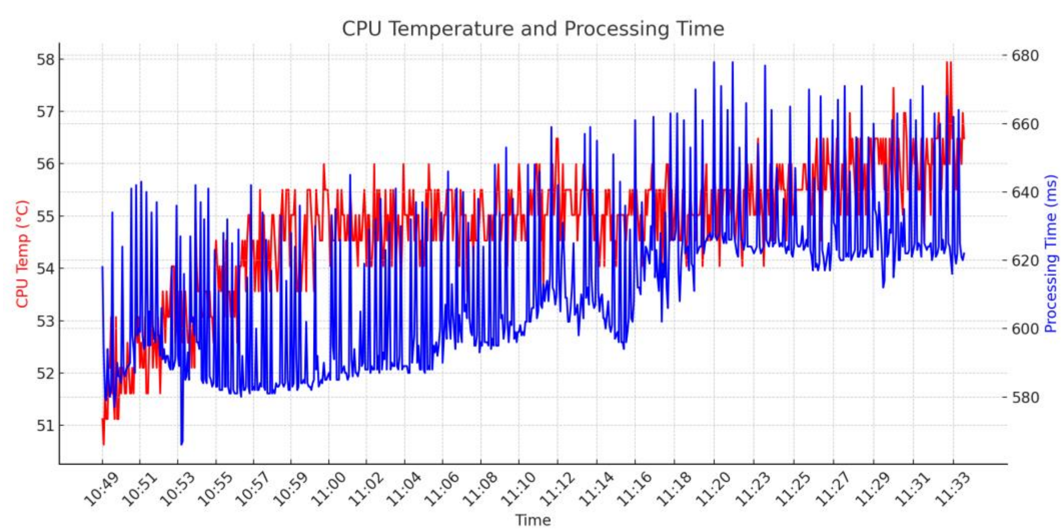


Figure 66: Raspberry Pi System Testing CPU Temperature and Processing Time

A software solution to the camera timeouts would be to add a watchdog into the program to allow for the algorithm to catch itself when there is an issue and reset the entire subsystem. This would allow for small errors to be corrected and the system to continue running autonomously without the need of intervention from the ski patrol. Additionally in order to keep the temperatures of the Raspberry Pi, at a more reduced level a vent would need to be added to the box that houses the electronics. This would allow for proper airflow and cooling of the Raspberry Pi. If the Raspberry Pi were kept at safer temperatures, it is likely that the processing power that is required to run the system would minimize, because the Raspberry Pi would not also need to be cooling itself.

Housing/Mounting:

While the housing subsystem achieves most of its goals in practice, there remains room for improvement. With everything fabricated, it was discovered that there was a lot more extra space within the housings than originally intended. Moving forward, a goal of cutting size and weight of the housings would likely be beneficial to decreasing costs and maximizing adjustability. If future power work allows the use of smaller panels, the system could become much lighter and likely more stable, as smaller panels would collect less drag from wind.

6. Bill of Materials

Table 19: Bill of Materials

Bill of Materials				
Item #	Description	Quantity	Total Cost	Link
Housing				
1	ML-92F Weatherproof NEMA Enclosure	1	$79.00	Polycase
2	Clear Red Acrylic Color Filter	1	$9.98	Amazon
3	Clear Green Acrylic Color Filter	1	$9.98	Amazon
4	ZQ-100806-14 Outdoor Electrical Box	1	$65.89	Polycase
5	WX-22 Panel	1	$10.81	Polycase
6	WC-24F Outdoor Enclosure with Clear Cover	1	$27.36	Polycase
7	ML-70F*1508 Plastic NEMA Enclosure	1	$49.20	Polycase
8	ML-70K ML Mounting Plate	1	$15.26	Polycase
9	Wire Glands	4	$4.18	CableGlandsDirect
10	PVC Reducer	2	$11.52	Home Depot
Detection				
10	Raspberry Pi Camera Module 3 Wide Angle Camera	1	$35.00	Adafruit
11	Raspberry Pi 4 Model B	1	$75.00	Adafruit
12	Detection PCB (Pi Sheild)	1	$38.00	Custom (Oshpark)
13	9 Pin header 2.54MM	1	$0.12	Digikey
14	2.5M Mounting Screws	8	$1.06	Digikey
15	Plastic Spacer	4	$1.21	Digikey
16	Nylon Washer 2.5M	16	$1.60	Digikey
17	Nylon Washer 2M	4	$0.40	Digikey
18	2M Mounting Screws	2	$1.48	Digikey
19	2M Nut	2	$0.20	Digikey
Communication				
20	MSP430FR2111	1	$1.13	Digikey
21	RFM95W (LoRa)2	2	$49.90	Adafruit
22	Push Button	1	$9.99	Digikey
23	Transistors	2	$2.50	Digikey
24	10 UF capacitor	1	$0.58	Digikey

25	0.1 UF capacitor	1	$0.10	Digikey
26	2 pin screw terminals	3	$1.08	Digikey
27	3 pin screw terminals	1	$0.59	Digikey
28	Custom Uphill PCB	1	$28.25	Oshpark(N/A)
29	2.5mm mounting screws	4	$4.24	Digikey
30	2.5Mmm nuts	4	$0.40	Digikey
31	2.5mm nylon washer	8	$0.80	Digikey
		Power		
32	Voltaic 50W panel	2	$178.00	Voltaic
33	LiFePo4 10Ah battery	1	$36.00	Eco-Worthy
34	LiFePo4 30Ah battery	1	$80.00	Eco-Worthy
35	12V/3.3V DC/DC converter	1	$9.00	Amazon
36	On/Off Switch	1	$10.00	Amazon
37	Bulk Wires	20ft	$35.00	Home Depot
		Mounting		
38	PolyStake XL	2	$42.00	Fall line
39	Square U Bolts	1	$21.59	Amazon
40	M5-0.8x16mm Zinc Machine Screw	12	$10.50	Home Depot
41	M5-0.8 Stainless Steel Lock Nut	12	$13.50	Home Depot
42	Solar Panel Bracket	2	$98.00	Voltaic
43	Mounting Brackets	8	$40.00	Custom (Aluminum 8x2x8)
44	5/16in-18 x 1-1/2in Round Head Machine Screws	2	$2.97	Home Depot
45	#8-32x1-1/2in Round Head Machine Screws	1	$1.47	Home Depot
46	6 ft Square Steel Tubing	2	$19.99	Murdochs
		Total Cost:	$1,092	

7. Acknowledgements

We would like to acknowledge all professors, and educators who helped us achieve our goals.

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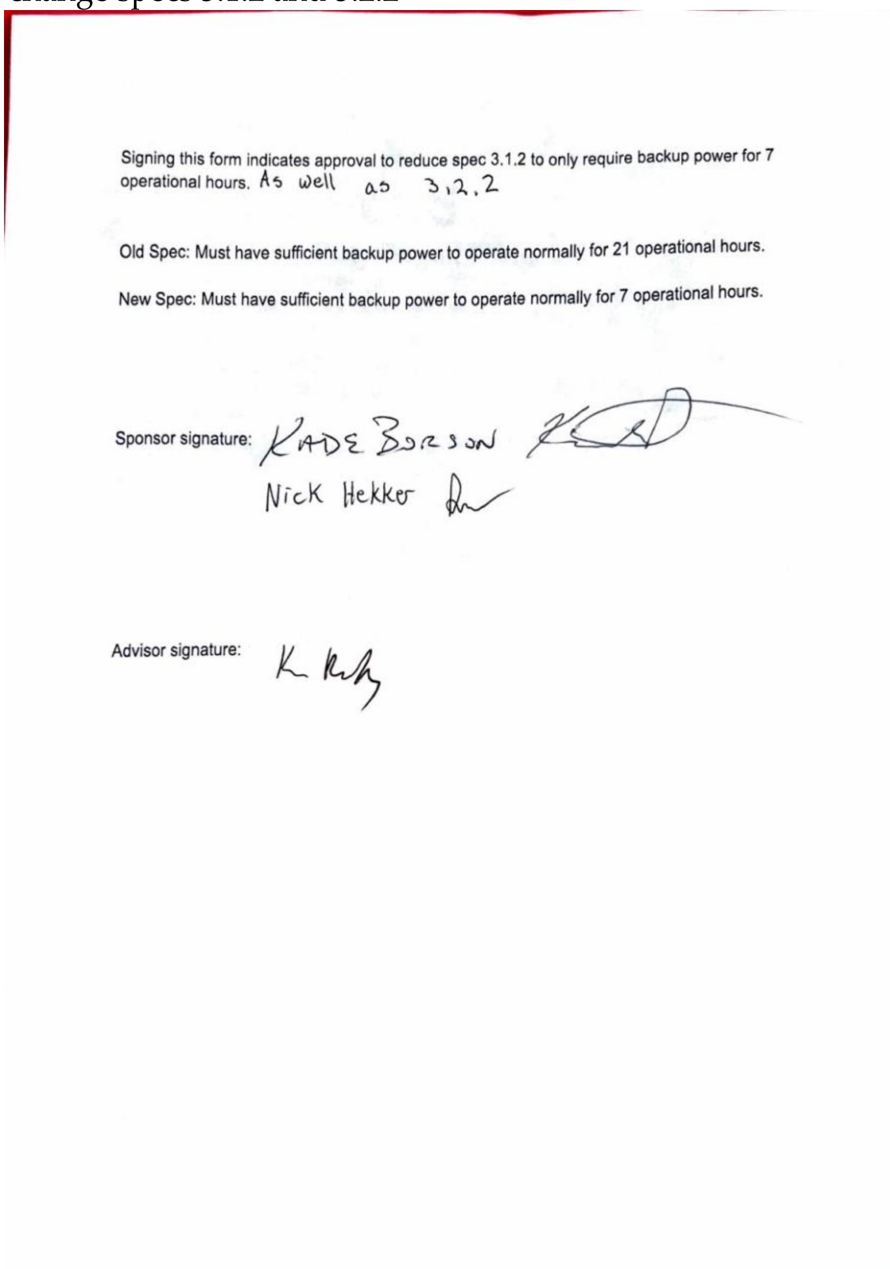
Appendix A (Title)

Approval to change specs 3.1.2 and 3.2.2



Signing this form indicates approval to reduce spec 3.1.2 to only require backup power for 7 operational hours. As well as 3.2.2

Old Spec: Must have sufficient backup power to operate normally for 21 operational hours.

New Spec: Must have sufficient backup power to operate normally for 7 operational hours.

Sponsor signature: KADE BORSON

Nick Hekker

Advisor signature:

Figure 67 : Approval to Change Power Specs

Spec 2.1.3 which stated "System is not meant to operate in visibility lower than 30 ft or when the terrain park is not operational" was moved to a constraint.