DroneX

Drone Detection System

Group 24

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April 25, 2023

Contents

1 Executive Summary

The goal of our project is to design a drone detection system that can detect a drone through visual analysis by camera, one normal camera in a specified location. The camera will be transmitting their live video feed through our Jetson Nano wireless module and our server will be receiving it. Our machine learning software will be custom designed to be able to find a drone that is in the livestream. The Jetson Nano will use the wireless module to transmit the video. The camera and pcb will be in a custom built waterproof case so it will be able to withstand the outside environment and other natural elements. The case will securely protect all of the electronics and provide a solid foundation to prevent from being moved around.

There are two primary points of focus for this project, the power system and the video analysis through machine learning. Both aspects take a significant amount of design, but will be designed very cost efficiently and accurately. The goal is to be able to build a circuit board with a color spectrum camera that will transmit their videofeed to a laptop for the visual analysis. However, we have only a limited amount of time, money, and resources; if we can prove to be effective with just 1 camera location, then we can prove the more cameras added the more effective and efficient our system would be for the user.

With a limited amount of time and money our system would not be practical to have a solar panel and rechargeable battery because if we did implement such a design the reality is it would not be able to hold a charge for more than an hour. The goal for our circuit was to be solar powered with rechargeable batteries so there is little to no maintenance. In our updated design it continues to be low maintenance, but there is a need for an extension cord of some kind to provide power to the system. The device case as a whole remains a small footlong box that proves to be portable and efficient. We will be following all Federal Aviation Administration (FAA) regulations in reference to testing the drone detection system.

Our drone detection device will be using machine learning inferencing of images captured by our input device (camera visible spectrum) to inform the user if a drone is present in the current area. To perform machine learning inference efficiently will require a certain module we will refer to as the AI accelerator. We will run a machine learning application with a dataset of drone image and video data until it is efficient in detecting drones. Once the application is polished and is able to effectively detect drones it will be ready for the DroneX Drone Detection system.

The DroneX system would not be a complete design without a user-friendly website that provides everything needed for a customer. The website will provide real-time alerts in case of a drone incursion, as well as the most accurate location of the drone possible, as well as the locations of the camera system.

2 Project Description

2.1 Motivation

Drone incursions at airports is a fast growing problem that has yet to be solved. Drone incursions cause several problems such as delaying flights, closing airports, and damaging aircraft, but unfortunately these are the best case scenarios when dealing with unwanted drones in an airfield. Drone incursions can lead to fatalities, either by damaging an aircraft which in turn crashes the aircraft, or a drone could be carrying an explosive device which obviously ends in fatalities. In this society, technology is fast growing, so much that it is estimated that 1 million consumer drones will be sold in 2022. Each of those drones are capable of carrying out the scenarios previously stated.

A drone incursion can be defined as any occurrence of a drone near an aircraft at anypoint in the flight, from terminal to terminal and everything in between. The FAA receives over 100 reports per month of drone sightings, from pilots, citizens, and law enforcement. A number that has dramatically increased over the last two years [2]. People who are not authorized to fly drones near aircrafts and airports are subject to criminal charges. In many instances people with no malintentions fly drones too high or too close to an airport without realizing it. Unfortunately this can lead to damaged drones, damaged aircrafts, or worse. In a recent report, a police drone in the area of an airport caused an in-air collision with a Canadian Flyer 172 which resulted in serious damage shown in the figure below [3]. Most recently a drone spotted in the DC area near Ronald Reagan National Airport this summer caused a shutdown of air traffic for almost an hour. This drone incursion led to 70 delays and 5 cancellations of incoming flights and 74 delays and 5 cancellations of outgoing flights [4]. These cancellations and delays are the best case scenario of drone incursions yet still take a huge toll on the airport communities.

Figure 1: Canadian Flyer 172 damaged by Police drone

It is clear that there has yet to be a system that tracks these incursions to be able to notify the FAA in real-time. The personal accounts of visual sightings is enough evidence to prove that these drones pose a highly dangerous threat. DroneX is a system that will be able to detect a drone both remotely controlled by someone and those that are not remote controlled through visual detection using machine learning.

Our cameras will be able to decipher between a drone and anything in the background through the utilization of machine learning. The system will not be limited to airports, it could also be a useful tool for places like schools, stadiums, prisons, etc.

2.2 Goals and Objectives

The project goals lay out the foundation of success for this project. When the DroneX System and website meet these goals the experiment will be a success and will provide a system that detects a UAV in a desired area apart from other natural objects such as trees, birds, etc. and notify the system user.

- Provide a safe and effective solution to drone incursion detection at airports and other secure locations.
- The system will be low cost
- The system will be low maintenance
- The system will run with an outside power source.
- The camera will record a live feed in a specified area.
- The camera system will use WiFi to transmit data to our server.
- The Jetson Nano will be home to the machine learning system which efficiently detects drones.
- The processed data will be moved from the server to API and from API to custom DroneX website for viewing.
- In case a drone is detected the video will be presented on the DroneX website.

2.3 Requirements Specifications

This section details the requirements that the device must satisfy in order for it to be successful. Requirement specifications must meet the needs of the customer or end user.

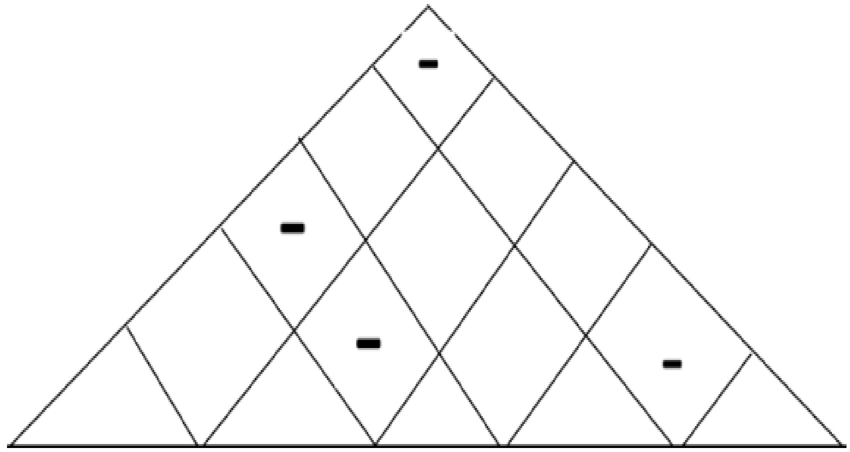
No.	Requirement	Value	Units
1.0	The device should be no larger than 11.5 x 6.5 x 5	11.5 x 6.5 x 5	inches
1.1	The device should stay operational without intervention for at least 6 months	6	Months
1.2	Device should alert user of an active incursion within 30 seconds of incursion	30	seconds
1.3	The Device will weigh no more than 10 pounds	10	pounds
1.4	The Device should be able to detect a drone ranging from 0–30 meters from the device.	0-30	meters
1.5	The Device should cost no more than $1000	1000	dollars
1.6	The Device will withstand temperatures ranging between 0-50	0-50	Celcsius
1.7	The device will withstand wind speeds of at least 60 mph	60	mph
1.8	The system should detect a drone with 1 types of camera	1	camera

Table 1: Requirements of the device

2.4 House of Quality

In Figure X, we provide the relationships between our marketing parameters and our engineering requirements. Our marketing parameters are qualitative aspects of our system that a consumer would be curious about. Our marketing parameters are as follows: low cost, low maintenance, reliability, ease of use, system accuracy, response time, and wireless capability. These marketing parameters are being compared to the engineering requirements which are quantitative aspects of the design. Naturally, we aim for high reliability, high ease of use, high system accuracy, and fast response time.

The engineering requirements consist of battery life, weight, cost, power consumption, and range of the system. In Figure X, the up arrow signifies a positive correlation, while the down arrow signifies a negative correlation. The double arrows show a more dramatic effect of the relationship, and when there are no arrows it tells us there is no correlation between the parameters.



↑ - positive correlation ↓ - negative correlation + positive polarity - negative polarity		**Battery Life**	**Weight**	**Cost**	**Power Consumption**	**Range**
		+	-	-	-	+
Cost	-	↓	↓↓	↑↑	↓	↓
Maintenance	-	↑↑	↓	↓		
Reliability	+	↑		↓↓	↓↓	↑
Ease of Use	+			↓		
System Accuracy	+	↓		↓	↑	
Response Time	-	↓		↓	↑↑	
Wireless	+	↓	↑	↓	↑↑	↑↑
Target		**> 2 days**	**< 50 lbs**	**< $300**		**0-60 meters**

Figure 2: House of Quality

To be able to achieve a low cost for the customer, all aspects of engineering requirements have a negative correlation. This is true because the more advanced the system becomes, the more expensive it will cost. For example, to make the system have a higher battery life, it will require a more expensive battery or a larger battery to power the system, in both cases it has a negative impact on the customer cost.

Not only do the marketing parameters and the engineering requirements have relationships with each other, but the engineering requirements also have strong correlation with each other. To increase the range of the system this would have a negative correlation to both the power consumption and the battery life of the system. Similarly, to be able to increase the battery life of the system we would need to spend more money, which obviously has a negative impact on the cost. Lastly, to achieve a lightweight system it is also going to be more expensive.

2.5 Block Diagrams

The following block diagrams are made to show a general overview of both the high-level overview and the hardware block diagram. Each block diagram shows the designated person responsible for each section.

2.5.1 Hardware Block Diagram

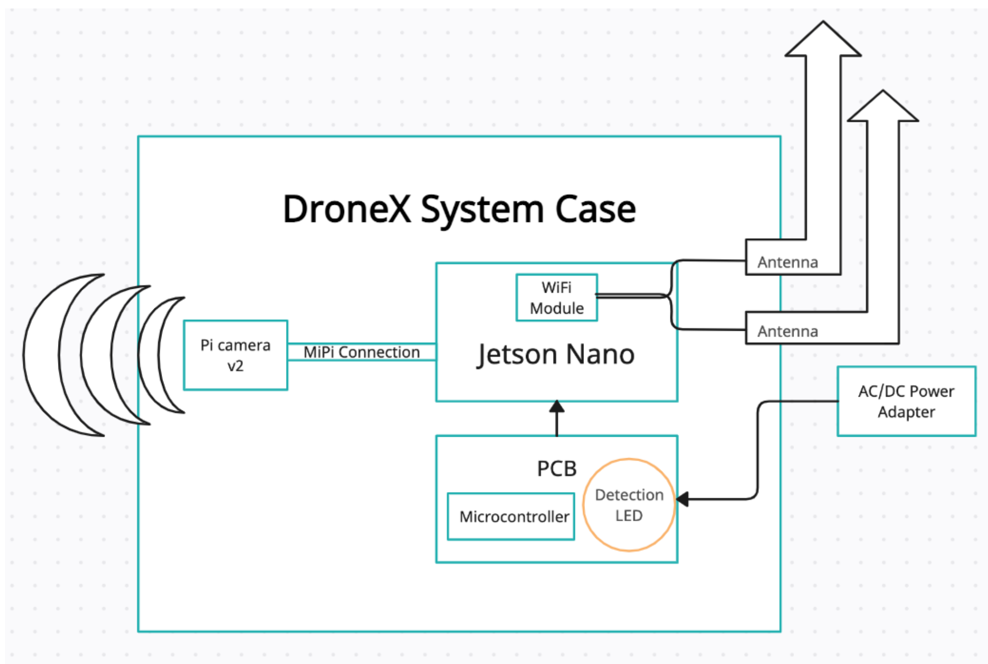


Figure 3: Hardware Block Diagram

The hardware block diagram shows the overview of the DroneX Drone Detection System. A single board computer will be powered by a solar panel and rechargeable battery, the team is responsible for the single board computer. The electrical engineers Nicholas King, Stephan Saturne, and Harrison Kennedy are responsible for designing a power module capable of delivering enough power to the single board computer. The power module must be able to be recharged by a solar panel and provide constant power at all times. Stephan Saturne is responsible for the rechargeable battery powered by the solar panel. Stephan Saturne will also be responsible for the solar panel and finding the best design for our system. Nicholas King is responsible for choosing the best GPS module and the best LoRa module for the system. Harrison Kennedy will be responsible for choosing the best cameras for our design, both infrared and color spectrum cameras.

The computer will have LoRa communications to transmit the data received to a Laptop that will house the machine learning for signal analysis. The team remains responsible for the laptop that houses the machine learning but will be led by Computer Engineer Youssef Barsoom. A GPS module will be connected to the single board computer so we can not only track drones but also the location of the DroneX sensors. Lastly, we also have a machine learning accelerator that will upload our learned machine learning code and run it at low power. Once the final data has been compiled it will be sent to the user. The team will be responsible for this aspect of the design due to its hardware and software features.

2.5.1.1 Senior Design 2 Update

The hardware block diagram in the figure above is the final product hardware diagram. Previously stated in this paper we decided to be more practical and throw out the solar power and battery idea due to short operation time capabilities.

2.5.2 Software Block Diagram

The user has two options through the system either to access a real-time view of the IR camera and normal camera and overlay of the drones detected in real-time or show a history of previous detections of drones through the web application. The Drone Detection Module is a module that will be responsible for receiving images in real-time from the normal camera and IR camera and will detect whether there is a drone in the images. This will be achieved using the Image Processing Model that will determine whether there is a drone in the image or not.

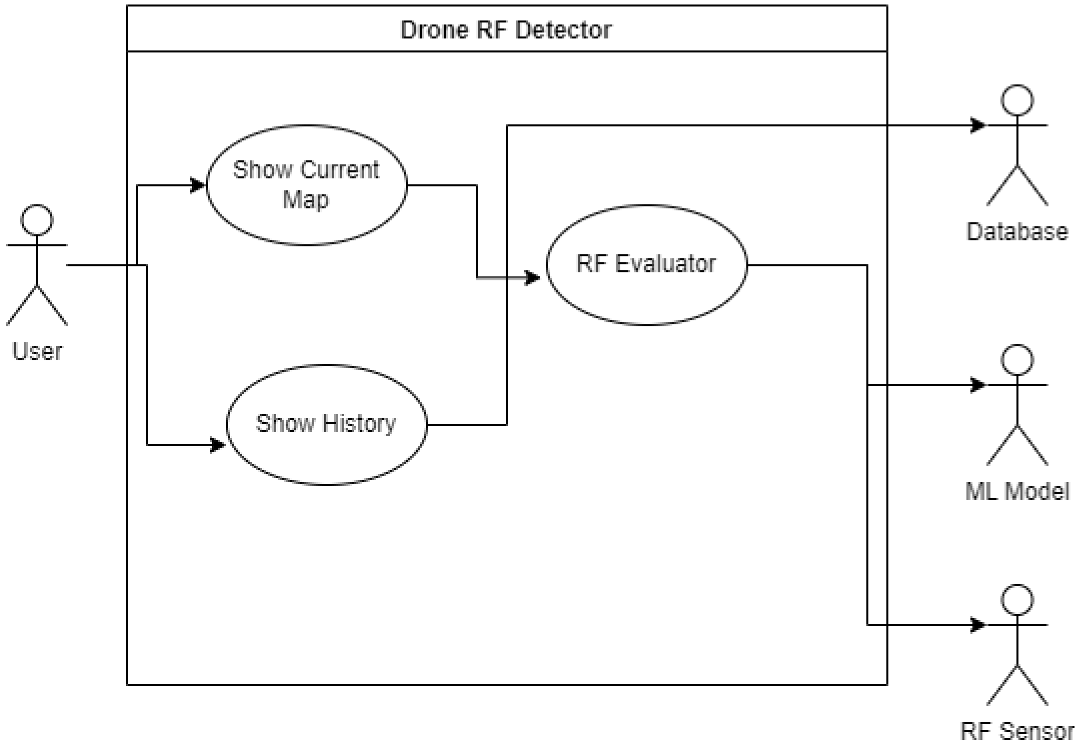


Figure 4: User Diagram for Drone Detection System

If a drone was detected, it will be saved in the database alongside any necessary data, for example the date and time of detection, and will send back to the user the location of the drone and the bounded area/section of the image that contains the drone. If the user were to choose the show history option, the user will have the ability to choose the date and time, the user wants to see if there was a drone during that time. If there was a drone during that specific date and time, the user will be notified of that matter.

3.0 Background

In this section, we provide information pertaining to the background knowledge that we used to inform our design decisions. The information in this section played an important role throughout the design process, especially in the motivation for the project. We discuss information regarding the different types of drone incursions, FAA regulations that must be followed at all times during our project, how drones communicate, and AI image recognition/machine learning.

3.1 Drone Incursions

A drone incursion is defined as a sudden invasion by a drone in a secure area. In other words, an unauthorized drone in an unauthorized location. The term drone incursions are most frequently used when referring to these events at an airport. However, there are several cases in which a drone encounter could be referred to as a drone incursion. Drone incursions cause several problems as stated previously in the paper, but there will be a more in-depth look into the background of drone incursions.

3.1.1 Airport Drone Incursions

All around the world drones have been spotted near airports by pilots, citizens, airport workers, etc. These incursions could be by pure accident, which most cases are. However, this does not rule out malicious intents when it comes to UAV usage near airports. Drones are capable of striking an aircraft and disabling it, whether it be the engine of a large aircraft, a propeller, a window, or any other parts of an aircraft. Drones are also large and strong enough to house an explosive device, which could be catastrophic. In any of these cases, drone incursions could prove to be fatal, whether there is mal-intent or not.

The best cases for drone incursions are by pure accident and the incursions only cause a shut down of the airport. Shutting down an airport causes delays, cancellations, and most important of all… money. When an unauthorized drone travels into airspace, the pilot of the drone is breaking the law and can be arrested. Yet, drone owners near London Heathrow, London Gatwick, Newark, Dublin and Dubai airports all have flown unauthorized and recreational drones near takeoff and landing airspace. In 2018, London Gatwick had a drone spotted near the airport which in turn canceled thousands of flights in just over 36 hours [5].

3.1.2 Wildfire Drone Incursions

Drone incursions are not limited to those of airports, they are also a big problem when it comes to wildfire prevention safety. Large wildfires require planes and helicopters to both monitor and extinguish the fire. UAVs are already small, quick, and hard to see, but when placed in a setting like a wildfire it makes them practically invisible. These can cause serious danger to those operating the firefighting aircraft and anyone on the ground near the fires. The current operating procedure for firefighters is if a drone is spotted near the scene of a wildfire no aircraft should be in the area of the fire until the drone has been confirmed to have left the area. While the drone is in the air the fire spreads and the aircrafts are unable to monitor nor extinguish the forest fire [6].

It is currently a federal crime and punishable by up to 1 year in prison to interfere with firefighting operations on public lands, which has been reinforced with an additional $20,000 fine imposed by the FAA. According to the US Forest Service, in 2019 there were over 20 documented drone incursions near wildfires, nine of which caused a shut down of firefighting operations [6].

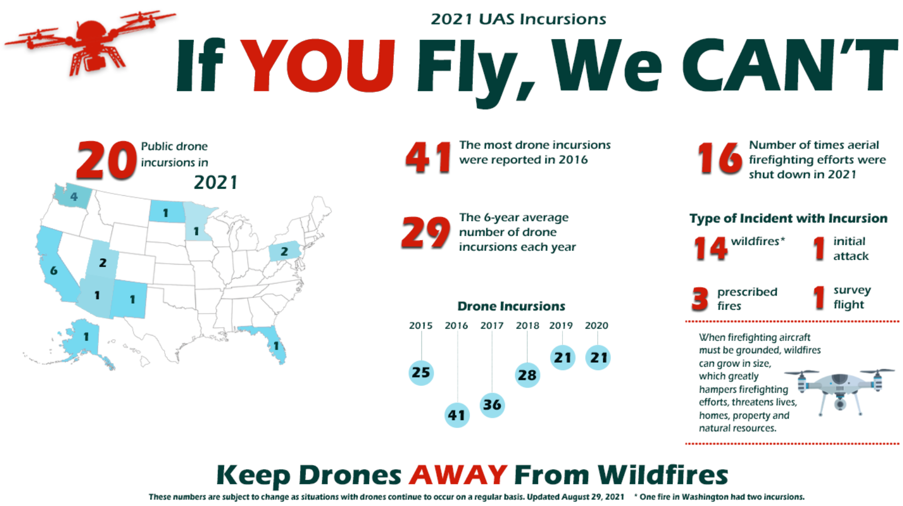


Figure 5: 2021 UAS Incursions over wildfires

3.1.3 Prison Drone Incursions

The Department of Justice had reported that the Bureau of Prisons have found an increase in drone incursions at their prisons. The intent of these incursions were one of the following: deliver contraband to inmates, surveil institutions, facilitate escape attempts, and/or transport explosives. Each of these terrible scenarios could end with fatalities, of not only inmates, but of prison workers or innocent civilians outside of the prison. In 2019, there were over 57 drone incursions which was a 50% increase from the previous year [7]. The Bureau of Prisons is severely in need of a drone detection system to put an end to these malicious drone missions.

3.1.4 Sporting Event Drone Incursions

During the 2021-2022 season, which ranges from early August to early February, the NFL counted some 1,400 incursions by drones during flight restrictions over and around stadiums. Drones have also inconvenienced, and sometimes menaced, Major League Baseball and other pro and college sports [9]. Drones are not allowed within a 3 miles radius of a stadium hosting a professional or college game starting one hour before it begins. With 1,400 incursions there are bound to be “nefarious” pilots out there with mal-intentions, repeating myself, these incursions can range from accidental crash to mass fatalities. Professional sport associations have pushed for lawmakers to prioritize drone incursions near sporting events so the players and fans can enjoy sports without having to worry about a UAV.

Drone sightings cannot be taken lightly and they will not be taken lightly because nothing is more valuable than the safety of passengers on an aircraft and anyone in the vicinity of the incursion.

3.2 FAA Regulations

The Federal Aviation Administration (FAA) is responsible for the safety of civil aviation. Some of their duties are safety regulation, airspace and air traffic management, air navigation facilities, civil aviation abroad, commercial space transportation, and many more. The FAA writes the laws, requirements, and constraints for all aircraft, manned or unmanned. The FAA regulations are vital to be known in this project because we must follow them strictly to prevent any violations.

Most drone incursions occur because UAV pilots are unaware of the FAA regulations in place for recreational flying. The default regulation for drones flying recreationally is if the drone weighs less than 55 pounds. In most cases drones weigh less than 55 pounds. To safely fly a drone you must follow the safety guidelines of an FAA-recognized community based organization, your drone must be kept within a visual line of sight of the pilot, and give way and do not interfere with other aircraft. As well as flying at or below FAA-authorized altitudes in a controlled airspace [10]. There are two Flight rules that must be noted, Instrument Flight rules (IFR) and visual flight rules (VFR). IFR means that the flight will operate in instrument meteorological conditions, also known as cloudy or poor weather conditions. Many aircraft fly under IFR for entire flights because it is the most efficient and it avoids bad weather. VFR means you can fly in visual meteorological conditions, meaning nice weather. Most training occurs in these conditions [12].

3.2.1 Airspace Regulations

All airspace is subject to FAA regulations, there is o such thing as "unregulated" airspace. For both this project and common knowledge it is important to know where one can and can't fly legally. Controlled airspace is near airports at certain altitudes where air traffic controllers communicate, direct, and separate all air traffic. It is given this title due to the fact that someone is controlling all aircraft in the airspace. Any other airspace will be considered uncontrolled. Generally, you can fly your drone below 400 feet above the ground in uncontrolled airspace, but to fly commercially in controlled airspace, it is required to get permission from the FAA. It remains the responsibility of the drone pilot to stay out of the way of other aircraft, not the private plane to avoid the drone [11].

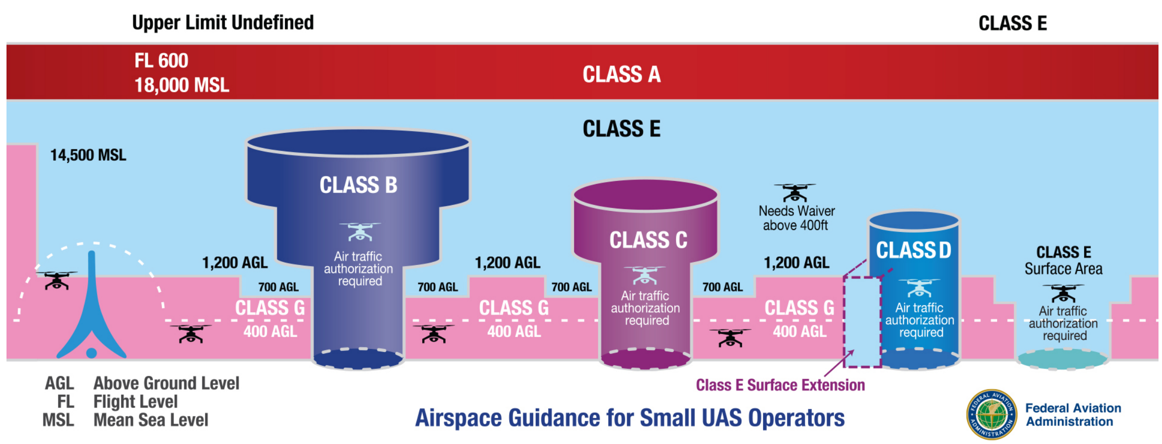


Figure 6: Airspace classes

The figure above is a fantastic representation of the different airspace classes and where a drone pilot would be allowed to fly. Class A airspace is between 18,000 feet above mean sea level (MSL) and 60,000 feet. Any operations in this airspace are conducted under Instrument Flight Rules and are primarily used by high performance aircraft, airline and cargo operations [12]. Class B Airspace is controlled airspace around the world's busiest airports. This controlled airspace starts at ground level and goes up to around 10,000 feet MSL. Each class B airspace is made up of different layers increasing in size as the altitude increases and boundaries depending on the shape or characteristics of the airport. As shown in the figure the layers are similar to that of an upside-down wedding cake. To be authorized to fly into or through a class B airspace all aircraft are required to obtain Air Traffic Control (ATc) clearance. Once this clearance is obtained the aircraft must follow their guidance completely [12].

Class C airspace is similar to class B airspace but deals with less busy airports. Again, it shares the upside-down cake layers which normally have a 5 mile radius from ground level to 4,000 feet, then a 10 mile radius from 1,200 to 4,000 feet. There is no clearance required to fly within a class C airspace, however it is required to communicate with ATC and their provisions of air traffic services must be obtained and maintained while in the airspace [12]. Class D airspace is a less restricted area around airports that are even less busy than class C airports; these airports still have an operating tower. The controlled airspace is from ground level to 2,500 feet above the surface. The airspace is custom to the airport but has only one solid layer. Two-way communications must be made and maintained before entering in a class D airspace.

Class E airspace is any airspace that is not classified like the previously stated classes. Most of the airspace in the world is considered class E. Control in a class E airspace is meant for aircraft operating under IFR, and VFR aircraft have freedom to move in and out of the airspace at their leisure. In most cases, class E airspace starts at 1,200 feet and goes up to 18,000 feet MSL. The interesting part is all airspace above 60,000 feet is also class E airspace [12].

Last but most relevant to this project is class G airspace. This airspace is uncontrolled and is not designated for anything. Pilots may operate as the like while following basic FAA regulations. This is the airspace that we will be testing our drone detection system in.

3.3 RF Signals

To fully understand UAVs and how they work it is vital to understand how they communicate with their remote operator, of course not all drones have a remote operator, but most recreational drones do. A Radio Frequency (RF) signal is an electromagnetic wave that is used in communication systems to transmit data through the air. These signals are used for carrying music to radios, video to television sets, and they are most commonly used for carrying data over a wireless network. Each RF signal has an amplitude and a frequency; the amplitude indicates the strength of the signal, which is generally represented by the power of the signal. The distance a signal must travel negatively affects the amplitude of the signal; while the signal travels through an open area it begins to lose power, this is called free-space loss. The atmosphere causes the modulated signal to attenuate exponentially; this leaves the requirement of a strong enough signal to reach the desired receiver.

The frequency of the RF signal expresses how many times the signal is repeated per second. This is measured in Hertz (Hz), the number of cycles per second. For example, a signal being transmitted at a frequency of 5.8 GHz means that there are 5,800,000,000 cycles per second in the signal. RF signals are good for long range use, especially when in line-of-sight, they are efficient in cloudy and foggy conditions, and operating an RF signal does not require a license.

RF interference occurs when more than one signal is present at the receiver at the same time at the same frequency, this can lead to errors. Some sources of interference can be mobile phones, microwave ovens, and bluetooth devices; these devices can decrease the performance of a wireless network due to the retransmissions and the competition on the network for use of the medium. The best way to deal with RF interference is by eliminating the sources of interference, or choosing a wireless network that operates in a different frequency band [14].

RF signals are also subject to multipath fading. Multipath fading occurs when a signal deflects off of physical objects and when it gets to the receiver it is either canceled out by a deflected signal or enhanced by a deflected signal. Multipath fading causes the transmitted information to be misinterpreted, causing errors in the data.

3.3.1 Why not detect drones through RF?

Drones emit RF waves to communicate with its controller and they are easy to be picked up on a receiver. So why is drone detection through RF harder to accomplish than through visual detection? The answer is because the frequency band that drones use to communicate with the controller is an extremely crowded one. Drones operate on the same frequency as WiFi, bluetooth, microwaves, garage door openers, security cameras, baby monitors, and the list goes on. Theoretically, if we had access to a secure area where there was no RF noise or interference we could easily detect a drone with 10 miles of our sensors, but then the system would not be applicable to the real world. The idea of RF drone detection is attainable, however for our senior design project, we simply do not have enough time or knowledge at this point to go through with this idea.

3.4 Drone Communications

Controllers use radio waves to communicate with their drones; these drones typically run on 2.4 GHz radio waves. Many drone controllers use WiFi to communicate which can be transmitted on the 2.4 GHz spectrum [16]. When receiving the RF signals being emitted by a drone we would essentially be eavesdropping on the communication between the controller and the drone. Due to the fact that most commercial drones communicate with the controller to update its status and receive commands there is a data link between the controller and the drone. Through the RF receiver we would be able to collect wireless data samples, analyze them, and detect if there is a drone in the area [17].

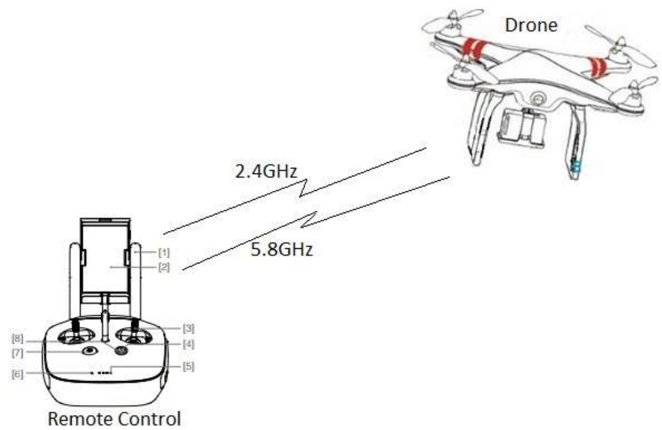


Figure 7: Drone communication on 2.4 and 5.8 GHz frequency

In today's market, drones are beginning to increase security of drones, also known as anti-interference capabilities, and they are accomplishing this by using frequency-hopping communication systems. Frequency-hopping, hopping across different channels over time, allows the system to communicate normally in complex electromagnetic environments. Drone communication signals include remote control signals, navigation satellite signals, and map transmission signals used by some aircraft types [17].

3.5 Artificial intelligence (AI) Image Recognition

Distinguishing between objects, places, and people from a 2 dimensional image does not even come close to a challenge for the human brain. For a computer it is not nearly as simple, and they face a tough time when trying to comprehend these images. In today's age technology has become advanced enough to where there are applications and specialized software that can decipher visual information. These programs are commonly known as "computer vision" and "image recognition". These terms are very broad and do not tell the entire story of how these machines can accomplish such a task. Computer vision uses deep learning or "machine learning" to perform tasks such as image processing, image classification, object detection, object segmentation, image colorization, image reconstruction, and image synthesis. Image recognition is sort of a subfield of computer vision, image recognition interprets images to aid the decision making process. It is arguably the most important task of the entire process [32].

Image recognition requires Artificial Intelligence because AI decodes images and has a predictive ability. The software and applications that are trained for interpreting images are intelligent. They are so intelligent that they have the ability to identify places, people, handwriting, objects, and actions in images and videos. To summarize, artificial intelligence is to feed a ton of data into the system, enough to where it can learn from the data and make informed decisions based on that data [32]. AI Image recognition is becoming so common in today's world that most people do not even realize they use it hundreds of times per day. The most common form of this is the facial recognition scan in iPhones that allows you to unlock your phone, use your face as a password, and even pay for things. More image recognition in today's world is the use of it in self-driving cars, such as Tesla. These cars use this technology to see pedestrians, stop signs, traffic lights, and pretty much anything on the road.

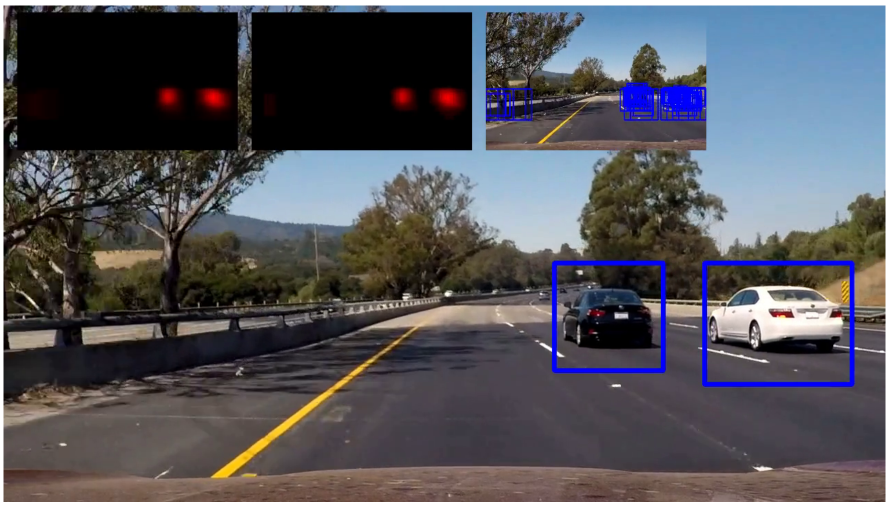


Figure 8: AI Image Recognition in action

Image recognition algorithms are what make image recognition possible. The process of building an algorithm for image recognition starts with the culminating and organizing of raw data. The computers then interpret every image either as a raster image or a vector image. Raster images are bitmaps where each individual pixel is arranged onto a grid. And vector images are a set of polygons that have explanations for different colors. By organizing data means to categorize each image and extract physical features from it. Geometric encoding of the images is converted into labels to describe the images. These labels are analyzed by the software; This allows the proper gathering and organizing of the data, which is critical for training the system. It is important because if the data quality is not accurate at this step, then the final model will not be capable of recognizing the correct patterns [32].

3.6 Machine Learning

According to Arthur Samuel, "Machine Learning is the study that gives computers the ability to learn without being explicitly programmed." In other words it is an application of artificial intelligence where a computer learns from previous experiences to be able to make predictions in the future. There are four categories of machine learning: supervised learning, unsupervised learning, semi-supervised learning and reinforcement learning.

In supervised learning, the machine experiences data samples with labels or targets for each example; the labels in the data aid the computer in building an algorithm or correlating features. Unsupervised learning deals with incoming data that has no labels and the machine must attempt to build a system to understand what kind of data it is working with. Semi-supervised learning is half of each of these, the computer deals with both labeled and unlabelled data to make predictions. And lastly reinforcement learning, this type of learning refers to goal-oriented algorithms, which learn how to achieve a goal over many steps. The machine/computer is able to maximize its performance in this type of learning by automatically determining ideal behavior within a specific context [18].

The different types of machine learning are all more efficient in their own unique scenarios. When deciding what kind of learning to choose, many aspects of the project must be considered. Some of these aspects are data size, quality and diversity, accuracy, training time, parameters, data points, etc. Below is a diagram that helps one find the most appropriate machine learning techniques for a specific project [19].

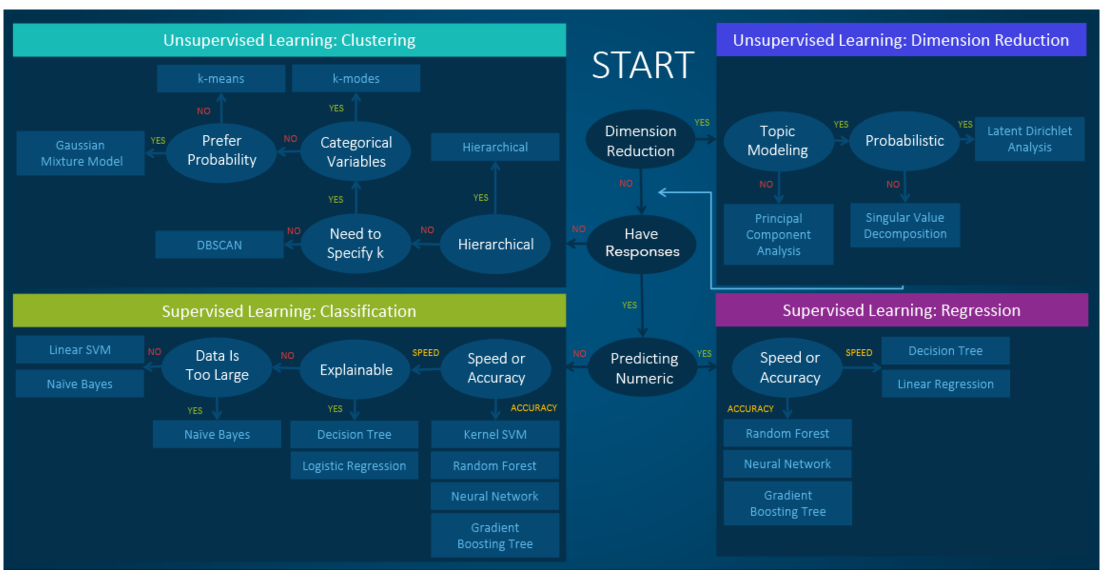


Figure 9: Machine Learning Algorithms Cheat Sheet

4 Related Standards and Design Constraints

This section will describe the standards contained in our device as well as design constraints our device must adhere to. Standards are an important aspect of design as it will allow for easier part acquisition and utilization. Constraints must be followed to ensure that our device functions properly when the device is fully built and operational.

4.1 Related Standards

Standards are an important part of engineering as they allow different designs and components to be interchangeable or interconnected with existing infrastructure. This allows for quicker implementation of ideas in our device as we do not have to create a completely new module or idea as it has been standardized. This will allow us to save a significant amount of time in our design not having to create new infrastructure as it already exists in the following standards we plan to use. These standards are listed as the following:Lora, LoraWan, USB, WIFI, and Cellular.

4.1.1 Lora

Lora is a fairly new protocol being developed by Semtech and patented in 2015. This protocol is a type of LPWAN(low power wide area network). Lora is unique as it uses the ISM spectrum. This spectrum is the unlicensed spectrum in the USA free for any one to use. The ISM spectrum in the United States is 900Mhz. When we refer to Lora we are only referring to the physical layer of the protocol. This means to use Lora an additional protocol is needed. [4]We decided on the commonly used LoraWan protocol and will discuss its functionality later.

The reason for using Lora as opposed to other similar protocols such as wifi or cellular technologies are as follows. When looking at each protocol we must consider three main aspects of performance: Range, Bandwidth, and Power. When looking at wifi it has a high bandwidth, low range, and low power. This makes wifi ideal for short range transmissions such as in a house or singular building but over greater distances such as we require wifi fails. Cellular is a high bandwidth, high range and high power protocol. This protocol was considered but due to its high power demand our sensors would need much more power input which made this protocol unfeasible. The Lora protocol is low bandwidth, high range and low power. Allowing for Internet of Things devices to connect to it from large distances up to 13 miles and not use a large amount of power. [4]Making it an ideal choice for embedded systems like we are trying to create. This standard does not have a high enough bandwidth however to support a large file transfer over this type of communication medium. This means in our application we would not use LORA to send video files real time as this is much too large and would take far to long over this network. Thus if we only wanted to send a ping or a small file for an alert this would be a feasible option for our project.

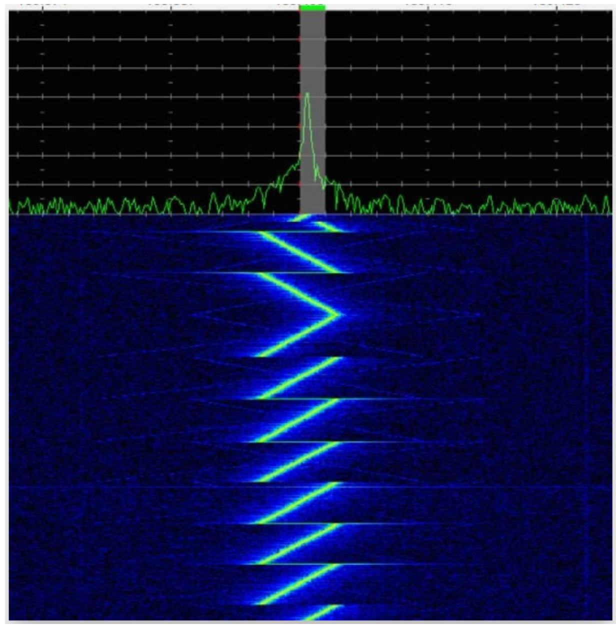


Figure 10: Shows preamble chirps from a Lora signal.

When examining how Lora works we first must understand the modulation technique that Lora was developed from. This is the Chirp Spread Spectrum(CSS). This modulation scheme uses chirps to encode data in its bandwidth. A chirp can be described as a linearly increasing or decreasing frequency of a signal from the top to the bottom of the bandwidth. When processing the above message high sensitivity is achieved by locking onto a long constant chirp that is transmitted before any data. The end of this long chirp is signified by a reverse chirp at the end of the long chirp. Then the data can be sent through. The data is sent through as a series of modulated chirps of different lengths referred to as symbols. Symbols is another way to refer to each individual chirp. Once received the signal is demodulated. During demodulation several orthogonal signals are able to be demodulated at the same time as long as they have different chirp rates. These different chirp rates are referred to as spreading factors(SF). The spreading factor has an inverse relationship to the chirp rate as a high spreading factor relates to a slow chirp rate.[4]

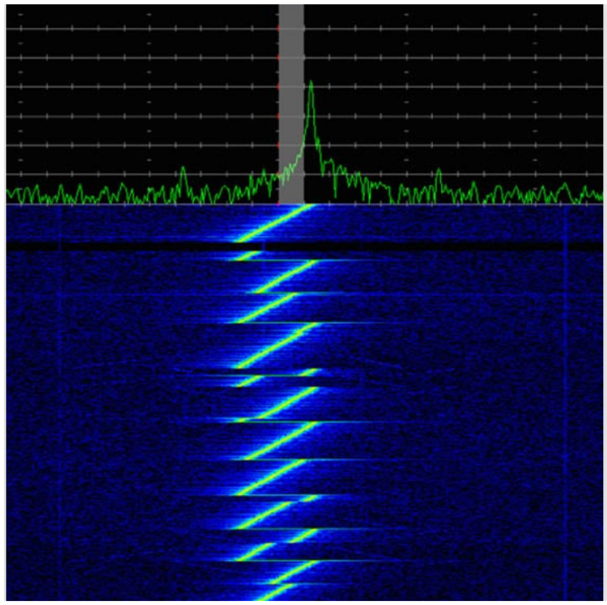


Figure 11: Shows modulated chirps from a Lora signal.

Another component of Lora that must be considered is how SF affects the transmission time and sensitivity of the system. The SF as said in the previous paragraph tells how many chirps are sent per second. High SFs therefore require more airtime to send the data to the receiver as each chirp has less total data in it. This can lead to a higher sensitivity but will keep the system on for a longer period of time as the system will be on for the entirety of the airtime. This causes a high power consumption when compared to the low SFs that have a low airtime.[7] However, the ideal proportion of SF to airtime is not high or low but more likely a place in between depending on the needs of individual systems.

4.1.2 LoraWan

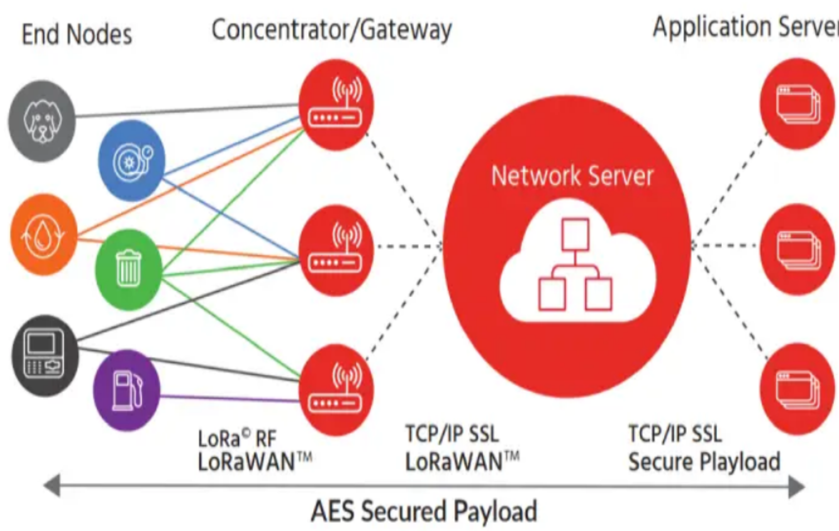


Figure 12: Shows LoraWan network topology (Permissions have been asked waiting for response)

LoraWan uses the physical layer of lora and builds upon it to create its own network protocol. LoraWan is one of many different protocols created for the Lora physical layer. However LoraWan was made to be public and has a wide variety of support from a variety of hardware vendors.[13] LoraWan also has the backing of a group created in 2015 called Lora Alliance. Lora Alliance was created with the sole purpose of advancing the LoraWan standard and how it is implemented into different hardware devices.[13] Lora Alliance also has the backing of large tech companies such as IBM which also speaks to the quality and longevity of the LoraWan standard.

LoraWan functions using a star-of-stars topology. This topology uses gateways that relay messages between end devices and a central network server. These gateways are connected to the network by standard IP connections. These standard IP connections act as a bridge that converts RF packets to IP packets as well as IP packets to RF packets. Using the long range capabilities described in the physical layer of Lora allows a single-hop link between the end devices and one or many gateways.[13] This also allows for bidirectional communication as alluded to by the bridge analogy. This allows for firmware updates to be sent to the system when needed. The next important note of this protocol is that LoraWan has three different classes of end devices depending on the application desired. Each of these classes will be discussed in detail in the following paragraphs.

Class A is the default class of LoraWan. This means that it must be supported by all LoraWan end devices. Class A communication is always initiated by the end device and is fully asynchronous. This class uses an ALOHA protocol, which means each uplink transmission can be sent at any time and is followed by two short downlink windows. The downlink communication must always follow the uplink with a schedule defined by the end application. Thus downlink must be buffered at the network server between uplink events. This allows for bi-directional communication as well as network control commands if they are needed. End devices of this class are able to enter low power mode sleep mode as long as is specified by the application, as there is no network requirement for periodic wakeups. This combination of features allows class A to be the lowest power option of the three classes while uplink communication still being able to be accessed at any time.[13]

Class B are described as having bidirectional end devices with deterministic downlink latency. Class B has the same initiated receive windows as described in Class A, however now the Class B devices are synchronized to the network using periodic beacons as well as open down link ping slots at scheduled instances. This requires more power then the Class A configuration but allows for the network to send downlink communications with a deterministic latency.This predetermined latency can be programmed up to 128 seconds and the extra power consumption is still low enough where this protocol can still be supported on battery operated devices.[13]

Class C has the same structure as the class A protocol, an uplink followed by two downlinks. However the Class C protocol even further lowers the latency on the downlink by keeping the receiver of the end device open at all times. This is happening even when the device is not transmitting. Thus the network server can initiate a downlink transmission at any time this means there is no latency. However this configuration causes a large drain of power as the receiver must stay active at all times. Meaning this protocol is not suitable for applications not using external power sources such as battery operated applications. There is an ability for a battery operated device to periodically use the Class C protocol when intermittent tasks such as over the air firmware updates are needed. This is done by switching between the Class A and C protocols.[13]

Class	Power Consumption	Latency	Transmission Pattern
Class A	Low	High	Asynchronous End device initiated
Class B	Middle	Middle	Synchronous End device initiated
Class C	High	Low	Continuous

Table 2: Shows a summarized version of each Classes pros and cons as well as their transmission patterns

Another feature of LoraWan is variable Data Rate(DR) settings. DR allows for a dynamic trade-off between message duration and the range of communication. This technology also allows for communications with different DRs to not interfere with each other. Allowing multiple signals to be sent in channels increases the overall capacity of the gateways. The network server manages the DR setting and Rf output power for every end device. This protocol is referred to as Adaptive Data Rate (ADR). The use of ADR allows for the central server to optimize the power of the end devices as well as their transmission power. The range of baud rates available to ADR range from .3 kbps to 50 kbps.[13]

The last feature to discuss associated with LoraWan is security associated with the standard. Having data sent securely is very important as to not have data leaked to malicious parties. This is done in 2 layers in the LoraWan standard. The first layer has a unique 128-bit Network Session Key which is shared between the end -device and the network server. The second layer uses a unique 128-bit Application Session Key that shares end-to-end at the application level. This results in having authentication and verification of packets traveling from one end-device to the central server and end-to-end packet encryption from the end-device to the end application server. This allows for the implementation of multi-tenant shared networks, with the benefit of the network operator having no visibility of the users payload data.[13]

4.1.3 USB

USB(Universal Serial Bus) is a common industry standard that has protocols for physical connections and how communication between the 2 connected devices takes place. This standard makes the connection between devices easier. USB has 4 generations USB 1, USB 1.1, USB 2, USB 3, USB3.1, USB 3.2, and USB 4. The USB 1 protocol has become obsolete however USB 2 and up are still used commonly today. The connectors used today are type A, B, and C with C being the newest and fastest currently in use. However type A is still the most commonly used and will be the connector used in our design.

4.1.4 WIFI

WIFI is a type of wireless communication that allows devices to connect together over a short distance using radio waves. This protocol uses the IEEE 802.11 protocol which designates the 60GHz millimeter wave spectrum as the operation zone of a set of networks. Due to the high bandwidth this network does not have a wide range only working in a max range of 300 feet without obstacles between receivers and about 160 feet between obstacles. This protocol also supports a much higher bit rate of data. This is because of the much wider bandwidth this protocol can send many more bits a second having a maximum bit rate between 1376 to 46120 Mbits per second. This is large enough to easily and quickly send large files in close to real time allowing for streaming of videos.

4.1.4 Cellular

Cellular is a type of communication protocol that allows devices to connect around a select distance between cellular towers. In our application we will be using a specific protocol called 4G LTE. 4G LTE is a protocol that has

4.2 Design Constraints

This section will describe the constraints associated with implementing our project design, as well as how these constraints have affected our project design. A design constraint is any obstacle that is imposed on the project. These constraints are not only ones related directly but can be related to group culture as well. For example, the time that meetings can happen every week may be influenced by another group member's job. In this way we are constrained not only by the building materials but by our own personal agendas and relations as well. In a perfect world constraints would be negligible but with a limited amount of resources and different rules and regulations already in place each of these constraints must be considered in our design. The constraints are as follows; economic, time, environmental, political, manufacturability, sustainability and ethical.

4.2.1 Economic Constraint

Cost will be a major constraint that will affect every part of our design. The team has to pay one hundred percent of the costs associated with the project. This will limit the quality of parts we are able to purchase as we will have to decide at which portion of our design we should use the majority of our budget. The components we can buy can be of several different qualities. From the hobbyist level which will have the lowest quality and smallest amount of features associated with the parts. The more hobbyist level parts used will require us to spend more time on the design of our PCB. However, the professional level of parts will have many features some of which will not be necessary for our project and cost significantly more then the hobbyist level. Thus it will be important to have a balance of hobbyist and professional grade parts in our design to maximize our budget and time available.

With this in mind we should in each step of our research process look at both hobbyist and professional grade parts. Thus in our research we will need to compare not only the quality of the parts but their price as well. The best part might not be the right part for our design as this could lock us out of a more important part such as a microcontroller. There is also the possibility of finding a late sponsor for our project who can help us in the funding department. Thus we should not stop looking for potential partners in our senior design experience such that we can create the best project possible.

4.2.2 Time Constraint

Time is always going to be against us in this project. There is a set deadline from the offset that has us completely finished by the end of April. Thus we must plan each section of this project accordingly. This starts with our design process which must be expedited as parts are still taking extra time to be shipped. Thus we can not wait until the last minute to create a design and expect the parts to arrive in time for testing. We must have our design completed before December and all parts on order at the same time. Such that after a small winter break we can dive into testing and configuration of our sensors. With this knowledge we must also not make the project too ambitious. Features we have chosen need to be feasible for the timeframe for which we can work. If time permits extra features such as more sensors can be looked into but as of now we need to be concise with our plan of action.

Time constraints also do not only refer to deadlines but also the time available from each member of the group to work on the project at any given time. Each of us unfortunately have bills to pay in order to live. Thus we must devote some of our time to working a job. We all also have additional classes other than senior design that also require our attention. Thus when we are planning out our time for the week we will not have as much time as we would probably like to work on our senior design project. Thus when we are working on our project we have to be concise and productive. There is a limited amount of time each week available for work, school, and leisure. Maintaining and operating with these three aspects of our lives in mind will be crucial in whether or not our senior project succeeds or fails. With that being said, understanding the time constraints of other group members and clearly understanding their schedules will help us avoid any rough patches in our senior design project. Maintaining a routine of meeting times each week and respecting the time of the other group members when we meet will allow for a successful project.

4.2.3 Political and Environmental Constraint

Political constraints of our design are mainly focused on air regulations and signal regulations that are controlled by the FAA(Federal Aviation Administration). The FAA has put limits on many aspects of design we have already looked to pursue. The FAA does not allow drones to transmit a common air frequency ADS-B out; this alone has taken away a mechanism for drone detection we have researched. The FCC (Federal Communications Commision) regulations on signals will also need to be adhered to as well. The FCC regulates all radio transmissions and any other signals that propagate in the United States. This means we will have to follow any guidelines the FCC has placed to have a successful project. This is especially important when we look at our infrared cameras as these must follow FCC guidelines on infrared output. Our signal communication propagation will also be under the scrutiny of the FCC as any signal we send will be under their jurisdiction.

The environment should always be considered when making anything. As the impact we have on the Earth is permanent and can affect more than just our generation but future generations as well. With this in mind our group will look to make this project as green as possible. The design of our project will be using solar energy to power our system. This is renewable energy clean energy that promotes a better energy system than if we used a direct plug into the power grid as a lot of that energy is not clean. Our product will have a very low environmental footprint as the manufacturing of our device should have little to no carbon footprint. The carbon footprint is the carbon put into the atmosphere as a result of the manufacturing of the device. The lack of plastic waste associated with our device design as well as the use of green energies such as solar make our environmental impact due to this project negligible. The plastics we will use will need to be biodegradable to ensure a healthier environmental impact.

4.2.4 Manufacturability and Sustainability Constraint

Manufacturability describes how easily the design can be produced. With the supply chain issues of 2020 manufacturability has become a foremost constraint as many easily accessible parts pre-pandemic are no longer as widely available. This means we can't just look at price and performance as availability of a part is also a possible issue. This also relates to our PCB as well, because the printing of PCB has long processing times to this day thus when ordering our board picking a manufacturer we must consider if they can make it in a time frame that is acceptable.

Manufacturability of our product will also refer to how easily we are able to produce this product in mass in the future. To this end when we are developing our product we must avoid using parts that are going out of favor such as old generation chips and microcontrollers. Adding these to our design could make future manufacturing of our device impossible. Forcing us to have to recreate the design again but with more updated parts. To avoid this we will not be using discounted discontinued parts in our design whenever possible such that our product can remain manufacturable for the longest time possible.

Sustainability refers to how long the product will last after completion. The best way we can maximize the sustainability of each sensor is going to be the case in which our components will be housed.Each sensor will be housed in its own independent case of the same design as we plan for the sensor parts to be identical. Thus our design for the sensor case must be able to withstand standard Florida weather conditions. This includes very high temperatures such as highs close to one hundred degrees fahrenheit, as well rainy conditions. Thus our sensors need to not only be water resistant to avoid damage from the rain but also heat resistant to avoid damage on hot summer days. Cold temperatures are not going to be a factor as extreme colds do not presently occur in Florida.

To further maximize sustainability of our project we will be using parts that are widely available for purchase. This will ensure that in the future we can easily replace damaged and worn parts without having to redesign the whole system. Having parts that can be easily modulated will also add to the sustainability of our project such that if one portion of the sensor breaks the sensor isn't broken but instead we can just replace the broken portion of the sensor and allow it to continue running for a significant amount of time.

4.2.5 Ethical Constraints

A major part of being an engineer is acting ethically. This is always a constraint that must be considered to avoid causing harm to others. In our design we must consider where our parts are being manufactured and try our best to avoid supporting companies that have unsafe or unfair working conditions wherever possible. Working ethically as an engineer in our project will also be making sure that our device can't hurt anyone due to some kind of malfunction. This means we need rigorous testing and multiple prototypes to ensure our device lacks defects that could endanger our community.

Another ethical aspect of the project is acting honestly when using others' work. This has to do with correctly citing and giving credit to the correct person or persons when their ideas or property is used. This includes asking permission for the use of images that are owned by other companies such as charts, graphs and tables that may be useful in explaining our project. Even if we accidentally forget a citation this would be an ethical failure thus when we finish our project we will need to go over our documentation several times to ensure we did not miss any citations.

5 Design Research

The purpose of this section is to look into potential parts used in the differing areas of our design as well as look into other similar products currently on the market. The areas of design research include, the single board computer module, the GPS module, the lora module, the Machine Learning technology, and the camera modules, as well as power module components such as the solar panel and battery. All of the parts discussed were compared to find the most efficient use of both cost and performance for our device. The supply chain is currently still not fully healed due to the coronavirus pandemic thus selecting available parts that will arrive in a timely manner was also considered in our research.

5.1 Analysis of Similar Existing Products

In this section we will discuss the current market of similar devices available for purchase. Since this is a fairly new field of study only being implemented in the past couple years many companies are pushing out all manner of solutions. Our exploration into these different types of drone detection products will help us in our design as we look into battery parameters, power requirements, and the ways drones are currently being detected on the market. There are multiple ways of detecting drones and looking at the advantages and disadvantages of each will be crucial in our design. Also looking at what is already on the market will give us a better idea as to what is realistically possible in our time and economic constraints.

5.1.1 Aaronia AARTOS Drone Detection

AARTOS is a drone detection solution part of the larger German company Aaronia, that has three different drone detection solutions. The types of detection options are; RF 3D detection and Radar detection. In the following paragraphs each of these products will be examined in detail. Showing the features available in each then comparing this to our current idea.

The first detection option, the RF 3D detection uses an array of RF antennas to detect drones in a radius around the device.[52]Depending on the variant of device design selected this detection system can have from 16 to 32 antennas in its array. The 32 antenna model allows for double the surveyed sectors as 16 antennas only offer 8 sectors of detection while the 32 antenna model offers 16 sectors. This device also has a wide frequency detection range. The frequency range of this device ranges from 400 Mhz to 8 Ghz. The 16 antenna array has a smaller tracking accuracy compared to the 32 antenna array with the 16 antenna array having a 4 to 6 degree accuracy. [52]The 32 antenna array has a 1 to 3 degree accuracy. When considering our own design compared to this we will be using a camera configuration to allow for visual detection of any possible drone incursions.This device allows for a 360 degree detection where we plan a directional detection creating in essence a fence around a protected area.

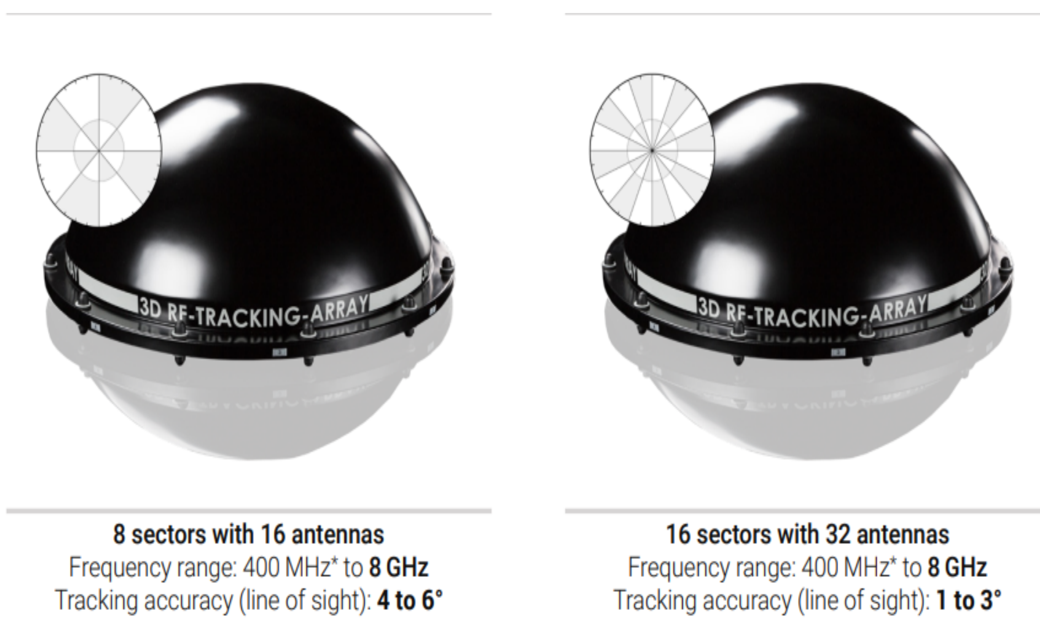


Figure 13: Shows the 16 and 32 antenna design created by Aaronia

The next device we will look at developed by Aaronia is Aaronia AARTOS DDS.
This product uses active radar to detect drones. The radar has a range of up to 8Km and similarly to the RF detection system has a 360 degree coverage around the radar. This radar system is also said to be able to distinguish drones from birds. Our own design will similarly be able to distinguish birds from drones using a machine learning algorithm to

teach our system the difference between drones and birds. This is a very important part of our project as the ability to distinguish drones from other moving objects such as clouds and birds will decide whether our project is a success or failure as a whole.

5.1.2 DroneWatcherRF

DroneWatcherRF is another drone detection device that uses RF to detect drone incursions. This device does not specify the total number of RF antennas in use in their device but the device does specify several ranges of frequencies that it can detect.[53] These ranges are from 900-990 Mhz, 2.4-2.48Ghz, and 5.5-6 Ghz. This is a wider range of frequencies then we are expecting to track as we are only expecting to look at frequencies of 2.4 and 5.8Ghz. This device also requires a direct plug in to an external power source. There are also 3 separate options used for connecting to the internet including wired ethernet, wireless such as wifi, and cellular. This product does not however offer Lora as an option for transmitting data. This device also offers what is referred to as plug and play integration requiring only a limited amount of configuration which they also offer in a web service.[53] Another thing to consider when looking at this model is their list of drone protocols included. As we have seen in our research each drone has a unique RF signature that is broadcasted from the controller to the receiver. Thus to be able to accurately track whether an RF signal is a drone or other device a preliminary reading of the RF signal is needed. Visual testing similarly will require a database to operate and function correctly.

5.1.3 Acoustic Drone Detection System Discovair

The last product we are looking at is an Acoustic Drone Detection System Discovair. This device operates by using 128 different individual microphone elements arranged in an array to listen for sound waves given off by operating drones.[54] Using this technology they say they are able to establish azimuth and elevation to the target in real time using digital signal processing. This is a similar idea to the one we have proposed with the caveat we are looking for visual detections as opposed to sound waves. This device also performs the signal processing inside of the main unit as opposed to sending the collected data to a central unit for processing. This could be a viable solution we could implement in our own design. However this device requires a relatively high output requiring 30W of power to operate. Thus this device does not offer battery integration as we plan to offer in our own design. The last thing to look at for this device is its user interface in which they use a web client or command and control system using the discovair API. This is similar to our own design ideas as we also have planned to use an API in our web client for data transfer.

5.2 Machine Learning Acceleration Technology

Our drone detection device will be using machine learning inferencing of images captured by our 2 input devices (cameras one visible spectrum, one IR spectrum) to inform the user if a drone is present in the current area. To perform machine learning inference efficiently will require a certain module we will refer to as the AI accelerator. This AI accelerator must meet several benchmarks to be considered for use in our project however. These benchmarks include but are not limited to low power consumption, compatibility with our input devices, high range of operating temperatures, as well as a high performance metric. This set of requirements is quite intensive for an average microcontroller thus we decided to use the AI accelerator for this task. With the influx of edge computing, AI, and machine learning in the past years there were many options available for us to pick through for this most important of components. Thus we selected the few we thought might be viable options upon first inspection and have below described each such that they can be compared. Through this comparison we will be able to select the module that best matches each of the parameters we have set forward.

5.2.1 Atlas 200 AI Accelerator Module (Model: 3000)

The first of the modules we inspected was the Atlas 200 AI Accelerator Module. This module firstly uses the AI processor Ascend 310. This processor has a 22, 16, and 8 TOPS int8. [46]This processing metric TOPS is used for neural network inference chips. TOPS refers to Trillions or Tera Operations per Second. This is primarily a measure of the maximum achievable throughput but not a measure of the actual throughput. This can be more easily understood with the following TOPS equation.

$$\textbf{TOPS} = (\textbf{number of MAC units}) \times (\textbf{frequency of MAC operations}) \times 2.$$

In the above equation MAC refers to multiply-accumulate operations. This Module also boasts 2 memory options, a 4GB and 8GB LPDDR4X with a bandwidth of 51.2 GB/s. This device has a very low power consumption rating using on average 6.5 watts for the 4GB configuration and 9.5 watts for the 8GB configuration. These basic performance metrics are in line with what we would need for memory and low power considerations as this module also has low power modes with a milliwatt sleep mode that can be changed in milliseconds to turn into the active mode.

This device also boasts many encoding and decoding options that we can use to process static and video images. [46]These options are listed below:

- H.264 hardware decoding, 16-channel 1080p 30 FPS (2-channel 3840 x 2160 @ 60 FPS)
- H.265 hardware decoding, 16-channel 1080p 30 FPS (2-channel 3840 x 2160 @ 60 FPS)
- H.264 hardware encoding, 1-channel 1080p 30 FPS
- H.265 hardware encoding, 1-channel 1080p 30 FPS
- JPEG decoding: 1080p 256 FPS; encoding: 1080p 64 FPS; maximum resolution: 8192 x 4320
- PNG decoding: 1080p 24 FPS; maximum resolution: 4096 x 2160

Having implemented decoding and encoding allows us to not have to create our own novel software in the system to implement decoding and encoding. This will significantly lower our production time when making our device. This module also supports three serial bus types; UART, SPI, and I2C. These protocols will be explained in greater detail in the microcontroller section but as of now it is important to note that having these bus types will allow for easy communication between this module and our microcontroller. The module includes a 144 BTB pin connector. This is way more than we could possibly need in our design but this does allow us to configure many devices to this module such as sending the images directly to the accelerator instead of the microcontroller first.

The Atlas 200 AI Accelerator Module has all the specifications we could want in an accelerator. It is power efficient and is prebuilt for video analysis such as the analysis we plan to perform in our own design. Its operating temperature is between -25C to 85C allowing the device to operate in more extreme conditions such as those found outside. It also boasts a small size no larger than a credit card with dimensions of 8.5 mm x 52.6 mm x 38.5 mm allowing for easy integration of the device into our system without having to create a large case for it. [46]The only downside of this device that has been found thus far is a very expensive pricing due to retailers being hard to find. The lowest price found was on Alibaba, a Chinese website shown to markup product prices, and it was found to be between $100 and $500. Thus to try to remedy this and possibly obtain the device for a more reasonable price we have sent the supplier of this device an email asking for pricing info and with any luck we can obtain this piece for a smaller cost with a possible student discount seen in other devices of a similar nature.

5.2.2 Coral Dev Board

The Coral Dev Board is the next module we will look at. This module was developed by Google. Being developed by Google this AI accelerator is made specifically to run machine learning inferences based on the Tensorflow lite module. This would greatly limit our options in our machine learning capabilities as other machine learning algorithm types are not supported. With this in mind the board does also have many upsides. This dev board has two possible memory configurations. The first is a 1GB LPDDR4 configuration while the other boasts a 4 GB LPDDR4.[48] The memory of this device gives us a wide range of use and allows for fast processing speeds.The total TOPS for this device is stated to be 4TOPS int8. The TOPS for this device is much lower then the preceding device but this number can be misconstrued based on the way the TOPS value was measured. As of now even though TOPS is the primary way for measuring neural network function there is not a standardized way to measure it making the number of TOPS real meaning left to the interpretation of the designers.[48]

This board is also fairly low power only requiring a 5V 2-3 amp input, as well as boasting a 2 TOPS per watt performance metric.[47] As stated prior the TOPS per watt value is hard to gather meaning from as the value for TOPS isn't easily understood nor stated in the design documentation. Thus knowing the input voltage and amperes is the best metric of power we can derive from the system. The input power is accessed in this module using a USB type C power port. Meaning direct wiring of this module could prove a problem as we must use the USB type C cable. This being said this device is not a high voltage application and should be able to be implemented into our design without issue as long as the USB type C is a nonissue.

This device also comes with 24-pin FFC connector for MIPI-CSI2 camera.[48] This would allow us to operate multiple cameras on this board directly if we so choose instead of feeding the camera into the microcontroller before sending the images to the AI Accelerator.The many pins on this device allow for many options of the physical hardware configurations.

The final consideration to make when discussing this board is of its price. This board is of a substantial cost for production as its 1 GB model the cheaper of the two still would require an investment of $129.99 before tax and shipping and handling costs.[47] While the 4 GB option is unavailable for purchase at the moment for unknown reasons. There are offered educational discounts for the 1 GB model that would help by lowering the cost by 35% if accepted.

5.2.3 Coral USB Accelerator

The Coral USB Accelerator is a usb stick that can be integrated into our system using a simple USB type C port. This is a very simple tool that would allow for integration into our device with very little design from us. Saving us a lot of time in our design process. The USB stick, though much smaller than the Coral Dev Board still boasts a 4 TOPS int8 using the Google Edge coprocessor. [49] This in essence means that this device has the same computational power of the previous device as it has the same TOPS value as well as the same manufacturer. Thus we can assume their metric for measuring TOPS to be the same and their relative processing power also the same.

This device also would require us to use one of the Raspberry Pi models such as Raspberry Pi 4 as the foundation. The Raspberry Pi alone does not run machine learning well however with the integration of the Corral USB Accelerator, we can use the USB's Edge TPU. Allowing us the benefit of the easy installation and programmability of the raspberry pi and machine learning. However the Raspberry Pi though not high cost as one of our team members already has one procured, is high in power consumption and that along with our team using a different microcontroller would mean basically using two microcontrollers in this system. This would lead to all of the benefits of the Coral USB being overshadowed by the power demands of the actual pi. We are however considering using the Raspberry Pi 4 as our main microcontroller in this configuration adding the USB Accelerator would not be a bad option. This has been turned down however as we believe as a group the limitations of the USB stick not having its own memory would bog down the system as a whole and put too much strain on the Raspberry Pi if we choose to use that microcontroller. Thus as a group we have decided that this device though low in cost and power consumption by itself would not fit our product plans.

5.2.4 NVIDIA JETSON NANO

The NVidia Jetson Nano is another AI accelerator we have considered for implementation in our device. This device is advertised as being easy to operate and implement machine learning inference without much prior knowledge. This prior support structure and many projects already completed using this device make it an enticing option. Thus we looked further into the specifications of the device.

The NVidia Jetson Nano has a 4GB 64-bit LPDDR4 memory.[41]This is comparable with the other AI Accelerators that have been previously discussed as they all use a LPDDR4 for their memory type. This device also comes equipped with a CPU and GPU to make for machine learning on the edge device quick and easy. The CPU used is the Quad-core ARM A57 @ 1.43 GHz and the GPU is the 128-core NVIDIA Maxwell.[41]

The power specification of this device is also low. As this device only requires a 5V input to operate. The power in watts of normal operation is only 10 watts and this device also has an idle state of 5 watts that can be used to also lower the power output of the device. [41]This allows us to be able to use this module in our current design as its low power form does not interfere with our low power system.

This device also has many other features that may also be useful in the development of our device. Including video encoders and decoders which will be useful when looking to process our video imagery of drone incursions. [41] These other features are:

- 4Kp30 | 4x 1080p30 | 9x 720p30 (H.264/H.265) video encoder
- 4Kp60 | 2x 4Kp30 | 8x 1080p30 | 18x 720p30 (H.264/H.265) video decoder
- Gigabit Ethernet, 802.11ac wireless
- microSD expandable storage
- Dimensions of 100 mm x 80 mm x 29 mm
- 40-pin header
- 12-pin header for power, UART, and related signals
- 4-pin fan header

The video encoder and decoder options will be vital in our implementation of our device. As stated in a previous section, not having to design our own novel software to encode and decode the videos will save a significant time in development. This device also uses many of the same bus specifications that our proposed microcontroller uses including UART, SPI, and I2C. These specifications will allow for easy integration from our microcontroller to this module and vice versa as an avenue for communication is already laid. The 40 pin and 12 pin headers are the means from which we can connect this device to our microcontroller as well as to other interfacing devices if we so choose such as our camera. [41] With this in mind, having many options for header connections is ideal at this early stage when we are still making many decisions as we go. This device has more header pins then we will need and having too many is a much better problem to have then not having enough.

The last thing we will discuss about this module in this section is price. This module, much like the other options, is not cheap. This device has a price of $149.00 before tax and shipping and handling costs. This is not the most expensive module we have seen but it is still a fairly expensive piece of equipment and thus this will need to be considered in our final decision.

5.2.5 Arduino Nano 33 BLE Sense

The Arduino Nano 33 BLE Sense allows for Edge Computing applications using TinyML. TinyML is broadly defined as machine learning applications and technologies such as hardware software and algorithms that can perform analytics on edge devices at very low power levels usually in the milliwatts. This TinyML is supported by a foundation of the same name that helps with the advancement and integration of TinyML devices. This module uses the 64 MHz Arm® Cortex-M4F. [45]This processor allows for quick and low power applications of machine learning to take place. Along with this processor the Arduino Nano 33 BLE Sense also boasts 256KB of SRAM and 1MB of CPU flash memory. This means we can use this board and upload our own machine learning program using the Arduino IDE to it. The drawback much like previous options is that this module only supports TensorFlow lite, limiting our options for machine learning softwares. This could be a problem if we decide to use a machine learning base that is not TensorFlow lite. This device also has a great deal of sensors including a temperature sensor and a barometric pressure sensor among others that will not be used in our design. These extra sensors will need to be powered off at all times to maintain a low power state that we want.

This device being low power is another specification of importance. With the device only requiring a 3.3V operating voltage with 1 milliampere.[45] The data sheet leaves all power consumption stats empty. Thus to know the power rating of this module we looked for an independent test. Finding that while in operation we can expect the board to consume about .166 watts based on the independent test of the system. The datasheet does however mention the operating temperature range which is between -40C and 85C. This is well above and below the extreme temperature conditions our device should be expected to face meaning that this module would be rugged enough to be incorporated in our design.

The Arduino Nano 33 BLE Sense unfortunately has a lack of pins. This device has a single UART pin, a single SPI pin, and a single I2C pin, this will greatly limit our possible design. Along with the aforementioned 3 bus pins we only have 14 I/O pins. 14 I/O pins should be enough for our application but this is still very low when compared to the other devices we are considering. This device also only has a single USB port for which we can possibly supply power but it lacks other functionalities. Thus communicating with this board and our other devices will be a design challenge.

5.2.6 Hailo-8™ M.2 Module

The Hailo-8 M.2 Module has the highest reported TOPS value at 26 TOPS. This should mean that this is the most powerful of the modules that have been looked at thus far. This is accomplished using 2 ARM Cortex-M4 @ 200 MHz MCU, with accompanying 640 KB SRAM. [58]This allows for unprecedented processing rates. The Hailo-8 also has a neural processing unit (NN-Core) which itself has a high performance multi stream and multi network core that also contribute to the 26 TOPS evaluation. This module also boasts both preprocessing and post processing of Deep Neural Networks using hardware offload engines. While also having three supported AI frameworks including TensorFlow, ONNX, and PyTorch.[58]

The Hailo-8 even with the aforementioned high processing power still has low power as a core function in its own design. This is important as it is working on edge Inferencing in which most devices are battery operated such as our own device. This module has 4 modes of operation that allow for different levels of power consumption. The normal mode will be the mode in which computations occur. This will lead the normal mode to also draw the most power of the 4 modes. Even so shown in the table below when operating in the normal mode the device is still considered to be low power based on the current and voltages used. The mode is doze mode. In this mode the module retains all memory and registered stored data which minimizes reconfiguration time. This allows this mode to operate using only 70 milliwatts. [58]The next mode is the sleep mode which minimizes power more by turning off the PLL and NN core logic. Allowing this mode to operate at 30 milliwatts. The last mode is hibernate. This mode turns off the neural network. Allowing it to operate using 4.5 milliwatts of power.[58]

Test Condition	VDD_CORE Peak AC Current	VDD_CORE AVG Current	VDD_TOP AVG AC Current	VDD_TOP AVG Current	Unit
RESNET 50, 1328 FPS[1] TT, 25C, VDD_CORE=0.8V, VDD_TOP=0.8V	4.23	3.84	0.404	0.29	A
YOLO V3, 31 FPS[1] TT, 25C, VDD_CORE=0.8V, VDD_TOP=0.8V	6.24	2.69	0.46	0.33	A

Table 3: Shows the operating voltages of the normal operating mode of the Hailo-8 device. These values can be used to calculate the average power in watts used by the system.

The many power options of this device are very tantalizing for our design as each allows us to configure our device and different off configurations when needed to save energy and even when on as shown by the above table the normal mode is still low power. This device also comes with a visual subsystem that we can take advantage of in our design. Having an ISP for a single sensor allows for our images to come to our Neural Network cleaner as it can reduce the noise in the image as well as increase the sharpness. This greatly increases the ability of neural networks to perform as it will perform poorer on images that are blurry. The module also supports the input of images using the Raw 8,Raw 10, Raw 12 and Raw 14 as well as outputs the RGB888 and YUV422 formats.[58]

This module also has the desired temperature operating range that would be needed for our device operating in varying conditions. As it is operable in temperatures between 0C and 70C both extremes of which we do not expect to reach when operating our novel device design. The only downside to this device that is currently seen is price as the retail value of this device is currently $219.00 without tax or shipping and handling costs. [58]This is hopefully being remedied by direct contact with the company that makes the Halo-8 and we can seek a lower price for this product.

5.2.7 Module Comparison

This section will house a table organizing each of the key attributes of each of the modules described above showing; price, power consumption, TOPS, and Neural Networks supported. After which any extra features that help with easing production will be discussed and a selection will be made.

Module	Price($)	Power(W)	TOPS	NN Supported
Atlas 200 AI Accelerator Module	$100.00-$500.00	6.5W-9.5W	22, 16, and 8	MindX
Coral Dev Board	$129.99	10W-15W	4	TensorFlow lite
NVidia Jetson Nano	$149.00	5W-10W	NA	NVIDIA Jetpack SDK
Arduino Nano 33 BLE Sense	$40.50	.166W	NA	TensorFlow lite
Hailo-8™ M.2 Module	$219.00	1.8W-3.5W	26	TensorFlow, ONNX, PyTorch

Table 4: Shows the comparison in features of the Modules we are considering for our AI Accelerator.

After reviewing the table there are clear outliers at several key spots of functions. The first being price, most of the modules are over $100 in price but the Arduino is more than half that at only $40.50. This would be a great cost save if we were able to implement this module in our device. Yet as stated before this price drop is also due to the lack of features associated with this module. As the Arduino Nano 33 BLE Sense had the least amount of features and pins of any of the other modules. Thus the price decrease when we consider the lack of features associated with this module is to be expected. The Arduino module also would require the most development time as it has the least amount of infrastructure available to it. Requiring a separate OS to run efficiently would mean that this model, though cheap, is not a good choice for our project and will not be considered.

The next function to look at is power consumption. This is probably the most crucial function of these modules. If they consume too much power during operation then the whole device could run out leading to a catastrophic failure of our device. Thankfully each of the above devices support a fairly low watt input going no higher than 15 watts in the worst case scenario. The best case scenario with the Arduino out of the race is the Hailo-8 module as it has a very low power rating of only a few watts.

The next function to look at is TOPS. TOPS is a metric of performance that describes how well a device can perform machine learning inference. The higher the number generally means a better performance, though it is important to mention that the measuring of TOPS is not currently standardized. Meaning that some of these values may be inflated compared to others and not show the exact representation of performance of the device. Yet this is still the main metric for measuring Edge Computing at this time. Thus when we are looking at the TOPS value we can see that Hailo-8 is clearly the highest. This is also a big advertisement for this device so it should be noted that this value in some way may be inflated, but taking it at face value this is the best processor for neural networks that we researched.

Finally we will look at the Neural Networks libraries that are supported. Most of the modules support the TensorFlow lite or TensorFlow machine learning application. This was developed by google and is very common. The module with the widest variety to choose from is the Hailo-8 having 3 separate applications supported. The Nvidia Jetson however supports the NVidia Jetpack SDK which has very good reviews on how user friendly it is to operate and learn with many tutorials and other infrastructure available when it is used.

It is due to these reasons that we have decided to select Jetson Nano module as our Machine Learning inference module. This module had many strong reviews which mentioned that it had a high processing power as well as a low output power. Even when operating at the peak it only is expected to reach 10 watts of energy. This is extremely low especially for a machine learning application. The only drawback of this option is the high cost associated with it. It is about $167 which is a significant cost for a single component.. This could cause us to have to use cheaper parts elsewhere in our design but since the main component of our design is the efficiency at which our machine learning inference occurs this seems to be the component to spend an extra bit on to make sure we get a high quality product with all the features that will make development and implementation of our machine learning algorithm as easy as possible. The Halo-8 module would have been selected if it had been available but it was unfortunately out of stock at the time of purchasing parts.

5.3 Camera Module

In this section we will detail the different types of camera modules we have considered for our project. Our current design will require two separate types of cameras. The first will display video in the color spectrum. This camera will only be useful during daytime operation as the visible spectrum isn't viewable in complete darkness. The second camera would operate in the Infrared spectrum(IR). This spectrum is not visible to the naked eye as it is outside of our visible spectrum. Cameras can operate in 3 different zones of IR. The first and most common is near infrared or NIR. This is the commonly seen black and white night vision mode that is used for security cameras such as CCTV. It is widely available but does not distinguish heat well between different bodies. The next is mid infrared spectrum MIR which describes cameras that operate in the mid infrared spectrum. Cameras within this spectrum are not widely available for purchase and the ones that are can cost well over a thousand dollars meaning they are not a viable option for our project. The final field of IR is far Infrared or FIR. It describes the frequency of IR past that of MIR and is also like MIR not widely available for purchase. With the few options available being well over a thousand dollars. This means our only viable option for IR imaging is NIR or derivatives of NIR technology. Thus distinguishing drones by their heat signatures will not be an option for our project however the black and white contrast of NIR during the day may still be useful in distinguishing drones in areas of crowded backgrounds such as a cloudy day or in front of a tree line in which our Machine learning algorithm may be tricked or unable to see the drone in the visible light spectrum. To this end we have gathered several potential options we could use to meet our needs. These cameras will both need to be relatively small in size to fit our design as well as low power as we plan to operate solely on battery and solar power.

5.3.1 See3CAM_CU27

See3CAM_CU27 - Full HD Sony® Starvis™ IMX462 Ultra Low Light USB 3.1 Gen 1 Camera is the first camera we will consider. The See3CAM is a fixed focus camera that can operate both in the visible spectrum and in the NIR region. [59]An important measure to understand when speaking about NIR is lux. Lux is the measure of brightness that a human being can see with the naked eye. In this measurement 0 is absolutely no light pitch black darkness and 150 is about the ambient light and a well lit room. With this measure in mind this camera is able to operate in conditions of 0 lux due to the NIR application.

This camera also has an HD color picture. This is accomplished by an onboard ISP(Image Signal Processor) That processes the image removing noise to create a crisper output image. In our application this will be crucial as the clearer the image is the easier it will be for machine learning algorithms to work properly. This camera is also a low power device. Requiring only a 5 volt input voltage with a max .424 ampere current to function.[59] The power required to operate this camera is also directly associated with the quality of image output. This is shown more clearly by the following table.

S. No	Resolution	Frame Rate (fps)	Supply Voltage (V)	Typical Current (mA)	Power Consumption (W)
1	640 x 480	120	5	270	1.35
2	1280 x 720	100	5	310	1.55
3	1920 x 1080	100	5	424	2.12

Table 5: Shows the relation of power to resolution of the aforementioned camera when the camera is compressing video using the MJPEG protocol.

The See3Cam is a highly functional low power option we will consider implementing in our device for both the color spectrum camera as well as the IR spectrum camera. As both the picture quality and power consumption for both standards is within our acceptable range. The price of this camera is the only major downside as it costs $199.00 before tax and shipping and handling.[59]

5.3.2 XNiteUSB2S-IR715: USB 2.0 Megapixel HD Monochrome Camera IR-Only 715 nm

The XniteUSB2S-IR715 is an IR only USB camera that could be utilized in our project. This camera offers a wide variety of frame rates and resolutions associated with these framerates.[55] Listed below each can be seen:

- 320X240 QVGA MJPEG @120fps/
- 352X288 CIF MJPEG @120fps
- 640X480 VGA MJPEG@120fps/
- 800X600 SVGA MJPEG@60fps>
- 1024X768 XGA MJPEG@30fps/
- 1280X720 HD MJPEG@60fps>
- 1280X1024 SXGA MJPEG@30fps/
- 1920X1080 FHD MJPEG@30fps>

As can be seen the higher the quality of the picture generally the lower the framerate of the associated video. Thus for our application we will be looking at 30fps to have the clearest image for our algorithm to view. Thus for this camera the configuration most likely to be used would be the 1920X1080 FHD resolution with a 30 fps.[55] The format that is allowed for this kind of video is shown to be the MJPEG, a common video standard for compressing videos. This camera also supports the Yuv2 compression format giving us a greater variety of design options for what kind of compressed videos our machine learning algorithm can decompress and use.

This camera also uses the USB 2 high speed protocol. This is a fairly common protocol and many of the microcontrollers we have already researched have this USB protocol available to interface with. This camera is also in the low power range of operation only requiring between .6 watts and 1.1 watts of power to operate.[55] This is crucial since our device will not be connected directly to the power grid and instead is a self contained system. The camera also offers several adjustable parameters that can be changed when the camera is in use. These are Brightness, Contrast, Saturation, Hue, Sharpness, Gamma, White balance, Backlight Contrast, and Exposure. Each of these parameters will effect how our final image is viewed so being able to actively adjust these parameters will allow us to create the clearest image possible. Most of our development with our microcontroller will most likely be performed on some version of the Linux operating system of which this camera can interface. This will save a great deal of time as the camera will in essence be able to plug and play and not require a lot of time or development to become functional. The only major drawback of this camera is the price. Due to it being an IR only camera it is more specialized and has a much clearer picture then a camera that sees in both IR and the visible light spectrum.[55] The price reflects this quality as this camera retails for $155.00 before taxes or shipping and handling costs. This is very expensive for a camera though this would provide the best quality IR image during both day and night we could buy.

5.3.3 IMX219-160IR 8MP Camera with 160° FOV

The IMX219-160IR is a color and IR camera. This camera operates in the color spectrum when there is sufficient lighting and switches to IR when it becomes dark. When looking at the color specifications of this camera we can notice that this is a 8 megapixel (MP) camera. [56]The 8 MP allows for a clear close to HD picture that will have a great deal of fidelity. The 160 degree Field of View (FOV) allows us to see in a 160 degree angle from the lens of the camera. This wide angle lens will allow us to cover a larger area with each sensor as they will have a wider cone of vision.[56] This camera does not use the MJPEG protocol that has been commonly used by the other cameras and instead sends the video stream via 8/10 bit RGB RAW output. This is as the name suggests RAW data. Meaning it is a packet of 1's and 0's we must decode to to receive an image. This is not as ideal as the MJPEG models but with extra design time can still be implemented effectively into our device.

This camera is made for the interfacing with the NVidia Jetson Nano. Thus if we decide to use that machine learning technology this would be an ideal supplement as they are already configured to work with each other. With that in mind this camera is also a low voltage device operating using a 3.3V load voltage.[56] This is in line with our design philosophy of low power modules to increase the maximum runtime of our device. The IR of this camera is also supplemented with 2 IR LED sensors. These pairs of sensors light up in the infrared spectrum not being visible to the human eye but in the camera it will look like two small spotlights are on increasing the visibility possible in lowlight and no light conditions that are expected with this kind of project. As our drone surveillance system will need to be operational 24 hours a day. The final consideration for this module camera is the price. This camera is very affordable costing only $24.90 before taxes and shipping and handling costs. [56]Thus even if we decide not to go with the Nvidia Jetson Nano this camera could still be considered for its high quality image at a low cost value.

5.3.4 e-CAM130_CURB - Raspberry Pi 4K Camera

The e-Cam130_Curb is a Raspberry Pi 4k camera. This camera uses an onboard high performance ISP to take very high quality video images. This camera is however a color camera only and can not see in the IR spectrum limiting its use for us. The color spectrum pictures obtainable by this camera are of superb quality. Allowing for 4k images at a resolution of 3840 x 2160 at 15 fps. [51]This is a low fps but since we are using the images for our machine learning algorithm the stuttering associated with a low fps is not of importance. The higher quality of the image the better our Machine learning inference will work. This camera can also operate in a temperature range from -30°C to 70°C which is far outside the extreme temperatures we can expect to see in the operation of our device.

This camera outputs the video file as an uncompressed UYVY format file that can then be used. This is much more convenient to work with than the RAW files that some of the other camera options were outputting. [51]Allowing us to not have to spend extra development time on setting up a way to process the data as it is already easily formatted and usable. This camera is also already formatted to work with the Raspberry Pi module. This is a module we are considering using for our microcontroller thus if we do go with the Raspberry Pi this camera will already be preconfigured to work directly with it further decreasing development time. The price of this module is higher due to the higher quality of the image we are receiving. The price is $99.00 before taxes and shipping and handling fees. However if we can afford to buy this model when all other components are purchased we will greatly increase the ability of machine learning inference to work correctly and efficiently as the images it would be using for detection would be clear.

5.3.5 Raspberry Pi 4 Camera IR-CUT Night Vision Camera Module

The IR-CUT Night Vision Camera Module is a color spectrum and NIR spectrum compatible camera. It operates with a 75.7 degree field of view which gives a fairly decent size cone of vision. The best resolution offered by this camera is 1080p.[60] This baseline HD should be of a clear enough picture for our application. Though the supplier of this module does not also show the fps of the highest resolution option. This is worrisome because we do not want to take near static images but want a stream for video. This camera is also preconfigured to work with the Raspberry Pi 4 meaning if we do choose to use the Raspberry Pi 4 as our microcontroller this camera would be preconfigured and have a plug and play aspect to it.

The supplier of this particular model lacks many wanted details for this camera that could affect our decision. The power output posted for this device is said to be 3.3V but as we know this is not a measure of power but of voltage. Such this can be considered a low voltage camera but it could be of significant power depending on the amperes that are being sent to it. The supplier also does not offer what kind of video output this camera outputs. Such that I can only assume that it is an output that can be readily used by the Raspberry Pi 4. This device does however come with 2 IR LEDs to improve night vision capabilities. [60]The power rating of these separate LEDs are unfortunately not readily available by the supplier of this device either. The only reason to continue looking at this device even with its very limited specifications available is due to the price point as the camera is priced at $22.99 before taxes and shipping and handling expenses. This is fairly cheap for a color/NIR camera meaning even if we bought it and it didn't work for our application we would not be out of our budget. Thus this camera can be seen as a low risk high reward gamble especially since many of the other options of cameras are of a much higher cost.

5.3.6 MLX90640 IR Array Thermal Imaging Camera

The MLX90640 IR Array Thermal Imaging Camera is an IR only camera that can also measure temperatures. In our application this feature will not be used but the ability to distinguish temperatures in the IR spectrum will allow a great fidelity of colors between images that are of differing temperatures. This will allow us to more easily distinguish objects in the foreground from static objects in the background. This camera also boasts a narrow FOV of only 55 X 33.[61] This will allow for the camera to gather information from further than if it had a wide FOV.

This camera has low input power levels needed for operation. This is ideal for our use as we need all of our components to be of the low power variety. This camera operates with a 3.3V/5V input voltage and an average current of 23 milliampere.[61] This camera also has a wide operating temperature range being able to operate in temperatures between -40C to 85C. [61]These temperatures are much more extreme then any that we would expect our device to operate in. The MLX90640 also uses the I2C protocol for the sending of information between the camera and microcontroller. This will save a significant amount of time in development as the camera wouldn't need any extra configurations added to make it work correctly. Allowing for a simple plug and play approach which is ideal whenever possible in our design to cut development time as low as possible such that we have plenty of time to test and tweak our machine learning algorithm.

Lastly the MLX90640 camera output picture unfortunately is not of the highest resolution. This camera only has a 32 X 24 pixel count.[61] This will lead to objects that are too far away not being distinguishable as they are only the size of a single pixel. This would make the distance at which we could start the detection of drones in the airspace shrink dramatically. Effectively making this camera unusable in our design unless we planned a 3 camera design in which the high contrast IR could be used to further help distinguish foreground objects from background objects. However in our application due to the size and scope for which we plan to be able to detect and warn of drone incursions this camera will not be considered.

5.3.7 Camera Comparison

In this section I will take each of the aforementioned camera options and place them in a table for easy comparing of their advantages and disadvantages. The table will show the name of the camera, the spectrum it runs in, the type of output file, price of the camera, resolution and power.

Camera Model	Spectrum	Output file	Price	Power (Watts)	Resolution
See3CAM	NIR/Color	MJPEG	$199.00	1.35W-2.12W	1920X1080
XNiteUSB2S-IR715	NIR	MJPEG	$155.00	.6W-1.1W	1920X1080
IMX219-160IR	NIR/Color	RAW	$24.90	3.3V	8MP
e-CAM130_CURB	Color	UYVY	$99.00	1.65W	3840 x 2160
Camera IR-CUT Night Vision Camera Module	NIR/Color	NA	$22.99	3.3V	1080p

Table 6: This table shows a comprehensive comparison of each camera module we are considering

Reviewing the above table we can see major discrepancies between the different camera modules. Starting off by looking at resolution we can see that the single spectrum cameras have a much higher resolution when compared to the camera modules. The e-CAM130_CURB having the highest resolution of the group would give a large amount of graphical fidelity in our final product. The Xnite and See3CAM both boast similar graphical resolutions but the See3CAM can maintain the high resolution at a much higher frame rate. The two remaining cameras are of a lower quality. More akin to that of the hobbyist level as many of their specification sheets were incomplete or displaying incorrect data types. However due to their cost being 4 times lower than that of their competitors it makes these cameras still a viable option. This is because even if we are unable to make the cheaper cameras work correctly we can still purchase the more reliable and authenticated cameras without much of a loss in cost.

Our current design will be using 2 cameras and because of this and our limited budget we will first be purchasing 2 of the IMX cameras. This camera does not have a very good specification sheet however it is of such a significantly less cost compared to the others that it is worth the time loss risk to save such a significant amount in budget. The cameras do have a return policy in place such that if they don't work we can return them within thirty days of receiving them and get a full refund. This could risk a significant loss in time but buying the camera now and testing it before christmas would mitigate this risk allowing us to spend the extra budget on other forms of materials and of higher quality microcontrollers or Machine learning inference tools.

If the IMX cameras fail to work for our design we will be forced to buy the Xnite IR camera and the e-CAM130_CURB cameras instead. These cameras have a much higher impact on our budget costing a combined $255.00 before taxes and shipping and handling fees. However these two cameras are the highest quality available and in a market that seems to be lacking cameras in general for this application these two fit very well. They both boast very high resolutions and both come with ISP pre-installed allowing for much clearer images that have less noise. The installation on both would also be very simple into our device as they are both USB cameras allowing for easy integration into our microcontroller.

5.3.8 Senior Design 2 Camera update

After purchasing the See3CAM and the XNiteUSB2S-IR715, we connected them to the Jetson Nano for testing. The See3CAM had taken days to set up due to prerequisites that we did not have as well as incompatible software. This led to much frustration and the lack of time to set up the XNite camera. In addition to the See3CAM taking a lot of time to configure, the resolution of the camera itself was unsatisfactory and did not meet our requirements leading us to researching more cameras that will provide a more clear picture.

The XNite IR camera needs additional IR light to be shined in the desired location for the camera to work. As students who never worked with the IR spectrum in this capacity we were unaware of this additional necessity, therefore leading to us cutting out the idea of two cameras and two live streams. However, we ended up using the IMX219-160IR, that we have previously looked into for a few reasons. First, it was easily set up with no prerequisites like the See3CAM, it was cheap, and most importantly it provided a clear image that would benefit our system the best.

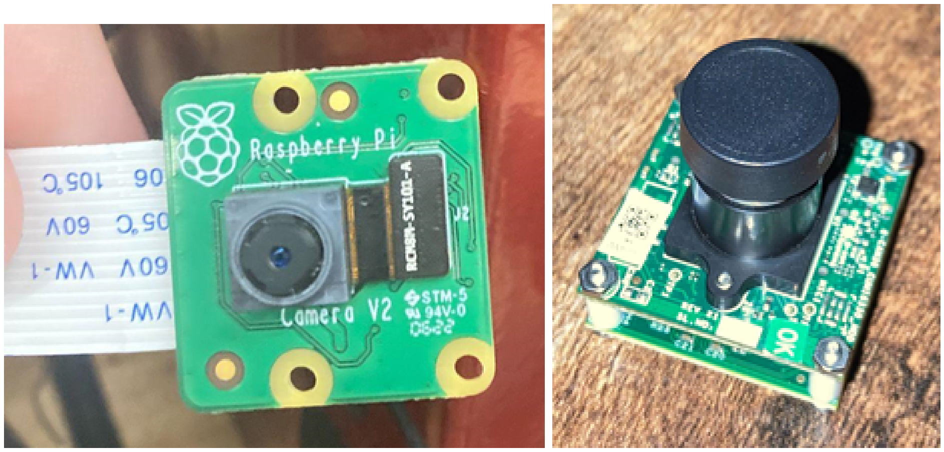


Figure 14: Pi Cam V2 and See3CAM

5.4 Lora Module

This section will detail the many possible options we have when selecting a Lora module. This component can be bought separately and integrated into our PCB connecting to an already established microcontroller. This option would allow for a lot of flexibility but would be design intensive as the microcontroller would not already have the Lora protocol. The other option we have is to select a microcontroller chip that comes with LoraWan already implemented on the chip. This is not very design intensive and would allow us to spend more design time on other areas of the project. There are also numerous LoraWan integrated microcontrollers already on the market.

5.4.1 MKL62 Lora Module

The MKL62 Lora Module is based off of Semtech's RF chip SX1262, which uses LoRa modulation technology for ultra-long communication distance, high anti-interference and low power consumption. The MKL62 is widely used in the field of wireless communication, for example, location tracking and other scenarios [21]. To recap, it is small in size and easy to be developed and integrated, it has a 10km communication distance, and uses ultra-low power (ULP) consumption. It also has high reception sensitivity [21].

This specific modules' dimensions are 14.6mm*10.6mm*2.8mm, and uses SPI as its communication interface. Its operating voltage is between 1.8 and 3.7 volts. The transmission current is 114 to 124 mA. The receiving current is 4.9 to 5.9 mA. Lastly the operating temperature is between -40 degrees celsius and 85 degrees celsius, which fits well within our required range. There is a stamp hole for an external antenna.

5.4.2 MKL62BA LoRaWAN Module

This LoRaWAN node module is designed and manufactured by MOKO technology Ltd. The module utilizes both the Nordic semiconductor nRF52832 and Semtech's Sx1262 chipsets. These provide ultra-low power consumption with outstanding wireless range using the LoRa radio link and local bluetooth low energy (BLE). This module requires no external components and has a built-in temperature compensated crystal oscillator (TCXO) to improve high-frequency stabilization, which means it can be used in a harsh environment for outdoor application [21]. This module also has a range of up to 10km.

This module has dimensions of 24mm*19mm*2.8mm, has 64KB of RAM and has a supply voltage of 3.3V. The maximum transmitter current is 120 mA, and the receiving current is 6.4 mA. The bluetooth specifications are that it is version 4.2, it operates on 2.402-2.480 GHz and ranges up to 50 meters. The operating temperature of this module is the same as the previous module, which is -40 degrees to 85 degrees celsius. An external antenna would need to be added to the U. FL connector.

The current price of this module is $19 from OzRobotics.com.

5.4.3 MKL110BC LoRaWAN Geolocation Module

This module is a fusion position module that integrates Semtech's LR1110 Edge chip and Nordic's Nrf series Bluetooth chip, which gives us the ability of bluetooth positioning, LP-GPS and WiFi positioning. It is high performance and cost effective. It supports the entire LoRaWAN frequency band, supports outdoor positioning, bluetooth, ULP, built in TXCO, and it has a compact footprint and pins with surface mount technology package [21].

This module has a stamp hole for LoRa antenna, 256 KB RAM, 50 total pins, and requires a supply voltage of 3.3 V. The max transmitter current is 118 mA while the receiving current is 6.4 mA. The bluetooth feature on this module is version 5.3. This module has the same operating voltage as the previous two modules, therefore it would meet our requirements in terms of temperature.

5.4.4 MKLC68BA LoRaWAN Module

This is a standard LoRaWAN node module designed and manufactured by MOKO technology Ltd. This module includes the Nordic Semiconductor nRF52832 BLE and the Semtech LLCC68 chipset, providing ULP consumption and excellent cost performance using LoRa radio link and local bluetooth connections. This module has a higher cost performance than the MKL62BA LoRa module and it is more suitable in close proximity scenarios [21]. Again this module houses bluetooth and built in TXCO for high frequency stability. It has a compact footprint and 33 pins with a surface mount package.

This module has an U.FL for an external LoRa antenna and an onboard bluetooth ceramic antenna. Different from the other modules, this module only has a range of up to 7km. The dimensions of this module are 24mm*19mm*2.8mm. It also has 64KB of RAM, and requires a supply voltage of 3.3 volts. The max transmitter voltage is 115 mA and the receiving current is 6.4 mA. Same operating temperature as the other modules.

5.4.5 The Seeed LoRa-E5

The Seeed LoRa-E5 utilizes a STM32WLE5JC microcontroller, which is the first to integrate both a microcontroller and a +22 dBm LoRa radio into one silicon wafer. The Seeed LoRa-E5 simplifies development with the STM32WLE5JC by embedding the clocks and main RF front-end circuitry into a single package, obtaining up to +20.8 dBm transmit output and -136 dBm receive sensitivity, and takes care of startup and shutdown power sequencing. All in a 12 mm*12 mm package. This microcontroller provides the best power consumption of 360 nA while in standby, 58µA while in low power sleep current (LPSleep), and 125µA while in low power run current (LPRun, < 2 MHz) with a max LoRa transmit current of 110 mA at 22 dBm. STM also provides a hardware abstraction layer for the device, and middleware, such as FreeRTOS and a FAT filesystem driver, and a LoRaWAN software stack all through their STM32Cube software package. The STM32WL utilizes an Arm Cortex M4 32-bit RISC core with 256 KB flash memory and 64 KB of SRAM.sa

This module also has a 12-bit ADC, which will be needed for the sensing sub-system. I/O connectivity is provided through and also has 3 UART controllers, 1 SPI controller, 1 I2C controller, programming pins, and 6 to 8 GPIO, depending on the UART configuration. However, the module does not come with an integrated U.FL connector, which increases the complexity of the PCB design and increases the number of components in the bill of materials. The reference design uses a short, straight trace to a SMA connector with a 0Ω resistor to allow the user to switch to a U.FL connector [33].

5.4.6 REYAX RYLR896 LoRa Module

The REYAX RYLR896 LoRa Module is a long range modem that provides ultra-long range spread spectrum communication and high interference immunity, while consuming minimum current. This module is certified by NCC and FCC. Some features of this module are the Semtech SX1276 Engine, excellent blocking immunity, low receive current, high sensitivity, and it is designed with an integrated antenna. The fact that this module comes with an implemented antenna is a bonus. GThis module is also used for home security and industrial monitoring so it is good for transmitting video. The typical supply voltage is 3.3volts.

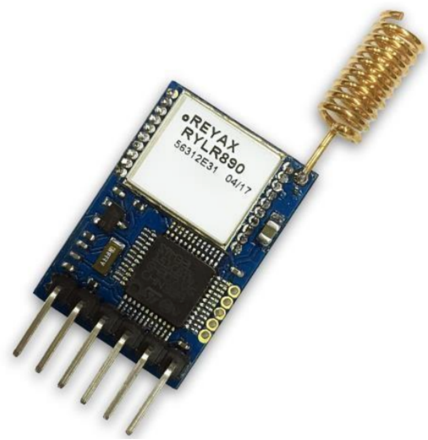


Figure 14: REYAX RYLR896 LoRa Module with embedded antenna

The REYAX RYLR896 LoRa module receives and transmits data through UART protocols.

5.5 Microcontroller

A microcontroller is a compact integrated circuit (IC) in an embedded system with a specific purpose. This project requires a microcontroller to be able to make computations, store memory, and provide the input and output pins for the operation of the device. The main job for the microcontroller will be to receive and transfer data from the drone detection cameras to the machine learning program on the computer through the unannounced LoRa module. The microcontroller will be able to communicate with the drone detection cameras, both the infrared camera and the normal camera, through UART, SPI, or I2C.

The microcontroller will receive its power from the DroneX custom designed power module. The power module will be solar powered and rechargeable, providing a constant source of the required voltage. The most important aspects of the microcontroller include specifications as type of communication, low-power modes, number of pins, size, and operating voltage. By looking at our hardware block diagram, we can see that it must be able to support the variety of features our system provides. Some of these features are GPS and LoRa module, the microcontroller must be able to fully support and control these components. To be able to fully support them the microcontroller must have enough pins and provide enough voltage to the components. The more efficient a microcontroller is with these specifications the cheaper our project can be.

One of the requirements for this project was to make the device have low power consumption. To have the system run on low power provides several benefits, it immediately extends the battery life, low power reduces the amount of maintenance required on the system, and the system doesn't have to use power while it is not actively computing or handling data.

5.5.1 UART Protocol

Universal asynchronous receiver-transmitter is one of the most used communication protocols between devices, it uses only two wires for its transmitting and receiving ends. UART is a hardware communication protocol that uses asynchronous serial communication with configurable speed. This means it does not require a clock signal. The UART device has a transmit and receive pin dedicated for either transmitting or receiving [26]. Each UART device requires one pin for transmitting and one pin for receiving. That is all that is required for it to function.

Start Bit (1 bit)	Data Frame (5 to 9 Data Bits)	Parity Bits (0 to 1 bit)	Stop Bits (1 to 2 bits)

Figure 15: The structure of the UART data packet.

This protocol defines that data is sent in a packet structure, shown above. A UART packet includes a start bit, the data frame, a parity bit, and one to two stop bits. While in the idle state, the TX line remains high. Communication begins when the TX line transitions from high to low for one clock cycle. After the start bit, the data frame, which contains the actual data being sent, is transmitted. This is performed by setting the TX wire to high when a 1 is transmitted and to low when a 0 is transmitted. This wire is sampled by the receiving UART device at the predetermined baudrate. Due to the fact that the parity bit is optional, the data frame may be eight or nine bits long. After the last data bit is transmitted, the parity bit is transmitted. This bit is used to tell if any data has been altered during the transmission process. The parity bit is calculated by summing the 1's and 0's of the data frame and then, depending on whether or not the sum is even or odd, the parity bit is set to 0 or 1 respectively. Finally, the stop bit is transmitted to indicate the end of the packet. This is done when the TX line transitions from low to high for one or two clock cycles.

5.5.2 SPI Protocol

Serial Peripheral Interface is one of the most commonly used interfaces between microcontrollers and integrated circuits such as sensors, analog-to-digital converters, digital-to-analog converters, shift registers, SRAM, etc. SPI is synchronous, so it uses a clock signal, full duplex main-subnode-based interface. This means that the data from a node, main or sub, is synchronized on the rising or falling edge of the clock. Both the main node and subnode can transmit data at the same time. SPI can be either 3-wire or 4-wire. 4-wire devices have four signals: serial clock (SCLK), chip select (CS), main out, subnode in (MOSI), and main in, subnode out (MISO). The main is what generates the clock signal and the data is transmitted between the main and the subnode synchronized by the clock. SPI can support a much higher clock frequency compared to that of I2C interfaces [27].

SPI communication begins by the master configuring the clock and then selecting the slave device which is set to low on the CS line. Then, during each clock cycle, data transmission occurs over the MOSI and MISO lines between the master and slave. The master reads a word of data, usually 8-bits, over the MISO line and the master transmits a word of data over the MOSI line. This exchange of words can occur multiple times. Once the final word has been transmitted between the master and currently selected slave, on the next clock cycle the next slave is selected and the process repeats.

5.5.3 I2C Protocol

I2C protocol, or Inter-Integrated Circuit, is a two wire serial interface. It is a bi-directional bus that is easily implemented in any integrated circuit process and allows for simple inter-IC communications. A serial data line (SDL) and a serial clock line (SCL) are used to minimize the amount of connections needed, a common ground is also used to carry all communications. The head device which clocks the bus addresses the other devices that are waiting to be told what to do and writes or reads data to and from the registers in these devices. The devices only respond when interrogated by the head device through their own unique address. Again, the I2C uses only 2 bidirectional lines, SDA and SCL. The I2C bus has the capability of supporting multiple devices, both head and lower level devices. The limitations of I2C is the capacitance on the bus, which is 400 pF, and the address space, 128 unique addresses [28].

The addressing scheme for I2C specifies the use of a 7-bit address. Each I2C device connected to a bus is required to have a unique address. This can be achieved by having a fixed unique address or a set of I2C addresses that can be selected from to ensure a unique address is used. It should be noted that the address bus does have eight bits total on the bus, however, only bits 7 through 1 are used for the address, while bit 0 is used for indicating the read/write status of the device. A 1 indicates that the master device will read from the slave device. Master devices do not require addresses, since they are the ones generating the clock and they address I2C devices connected to the address bus.

5.5.4 Microcontroller Candidates

Below are several candidates of microcontrollers available for us to investigate and research. Each of the candidates will have their individual features and specifications compared. The microcontroller that will be selected will be the best fit for the DroneX Drone Detection System.

5.5.4.1 MSP430

The MSP430 chip is one of the most popular microcontrollers in the world, which comes from the Texas instruments family. It is a mixed-signal microcontroller. The MSP430 microchip can operate with a current of less than one milliamp, meaning its power consumption is very low. The one reason why MSP430 uses low power consumption is the fact that it has the capability of wake-up times below one microsecond, which allows the microcontroller to stay in sleep mode longer which minimizes the average current consumption. There are some very useful peripherals part of the msp430 that our desired microcontroller needs to have, such as an internal oscillator, timer, watchdog, USART, and I2C. MSP430 typically does not have an external memory bus. It is limited to its on-chip memory. The MSP430 incorporates a 16-bit RISC CPU, peripherals, and a flexible clock system that interconnects using a von-Neumann common memory address bus (MAB) and memory data bus (MDB). Partnering with a modern CPU with modular memory-mapped analog and digital peripherals, the MSP30 offers solutions for demanding mixed-signal applications [30]. The MSP430 has a lot of great features that some other microcontrollers do not have such as:

1. Ultralow-power which extends battery life.
2. High-performance analog ideal for precision measurement
3. Extensive vectored-interrupt capability.
4. Optimized for modern high-level programming.
5. Permits flexible code changes, field upgrades and data logging in system programmable Flash.

Modern process control system has become increasingly more complex and so does the requirement for embedded processing with individual sensor units. MSP430 is used in almost every embedded system such as industrial sensing and communications, energy harvesting (renewable energy), and building automation (access control and security). Below is a block diagram that shows a typical architecture of an MSP430 [30].

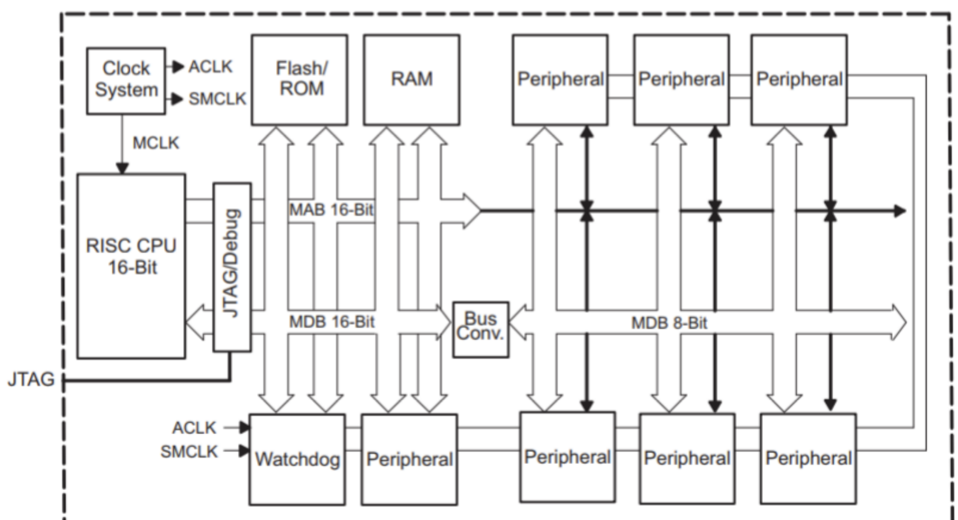


Figure 16: Architecture of a MSP430

5.5.4.2 Raspberry Pi

The raspberry pi is a small and affordable computer, and a single-board microcomputer that is being used today to learn and teach basic programming. The raspberry pi is known for more processing power than nearly all microcontrollers due to its power consumption. It lacks the hardware control and other peripherals found in microcontrollers. Microcontrollers such as the msp430 family are well-known peripherals for reading sensors, controlling hardware, and facilitating low-power communication. Though the raspberry pi may process information faster, the microcontrollers consume way less power which makes it very accessible for low-energy electronic devices.

5.5.4.3 MSP430FR6989

The Texas Instruments (TI) MSP430FR6989 is a suitable option for this project, given its reliability and power. The board is easy to implement, with the detailed documentation provided by Texas Instruments (TI), along with the experience we all have used this board in Embedded Systems labs. The TI MSP430FR6989 microcontroller has a 16-bit RISC architecture running on a 16MHz clock. This microcontroller has 83 GPIO pins. Regarding memory, it also has 128 KB of FRAM and another 128 KB of flash. In active mode, it has a maximum power consumption of 100 microAmps/MHz, and in low power, the maximum consumption is approximately 17 microAmps/MHz at worst operating conditions. The operating voltage for the MSP430FR6989 is between 1.8v and 3.6v. We can use this microcontroller to receive and transfer data from the drone detection cameras to the machine learning program on the computer through the unannounced LoRa module. We can also use this microcontroller to communicate with the drone detection cameras, both the infrared camera and the standard camera, through UART, SPI, or I2C. The MSP430FR6989 would be an excellent choice for the DroneX Drone Detection System because it has all the features we need for our system. The onboard features of the TI MSP430FR6989 include:

- 12-bit ADC
- Five 16-bit timers with compare and capture modes
- SPI, I2C, and UART
- Operating Voltage between 1.8V and 3.6V
- Clock Speeds up to 16 MHz
- LCD Screen

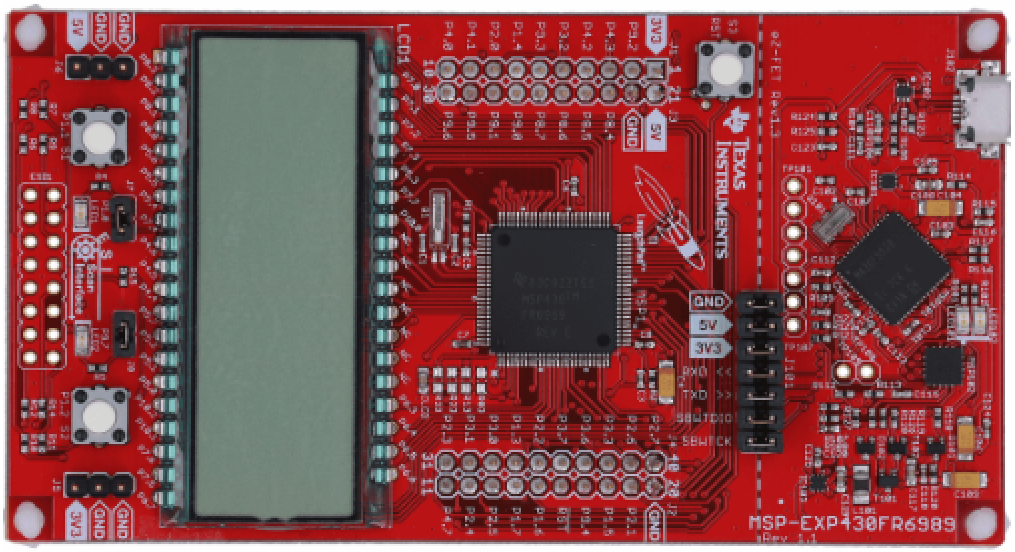


Figure 17: Texas Instruments (TI) MSP430FR6989

5.5.4.4 MSP432P401R

The Texas Instruments (TI) MSP432P401R is another excellent option for our project, it's a real-time operating system. The MSP432P401R has a low-power 32-bit Arm cortex M4F that runs up to 48 MHz, this vision of the MSP consumes approximately 95 microamps/MHz, and it only requires 14 MW of power. The MSP432P401R is very suitable for our drone detection project. It has 256KB of flash memory, 64KB of SRAM, 32KB of ROM, Four 16-bit timers with capture, compare, or PWM, two 32-bit timers, and an RTC. This board has eight serial communication channels, including I2C, SPI, UART, and IrDA [40]. The microchip inside this microcontroller contains wi-fi, Bluetooth low energy, sub-1 GHz, and host MCUs. The MSP432P401R has a max operating power ranging from 1.65V to 3.7V. We can use the MSP432P401R to receive and transfer data from the drone detection cameras to the machine learning program on the computer through the unannounced LoRa module. This microcontroller has 2C, SPI, and UART serial communication channels, which means We can also use this microcontroller to communicate with the drone detection cameras, both the infrared camera and the standard camera, through UART, SPI, or I2C. The onboard features of the MSP432P401R;

- Four 16-bit timers with capture, compare, or PWM.
- 32-bit timers, RTC.
- 256KB of flash memory.
- 64KB of SRAM.
- 32KB of ROM.
- wi-fi, Bluetooth low energy, sub-1 GHz.
- SPI, I2C, and UART communication.
- Operating Voltage between 1.65V and 3.7V.

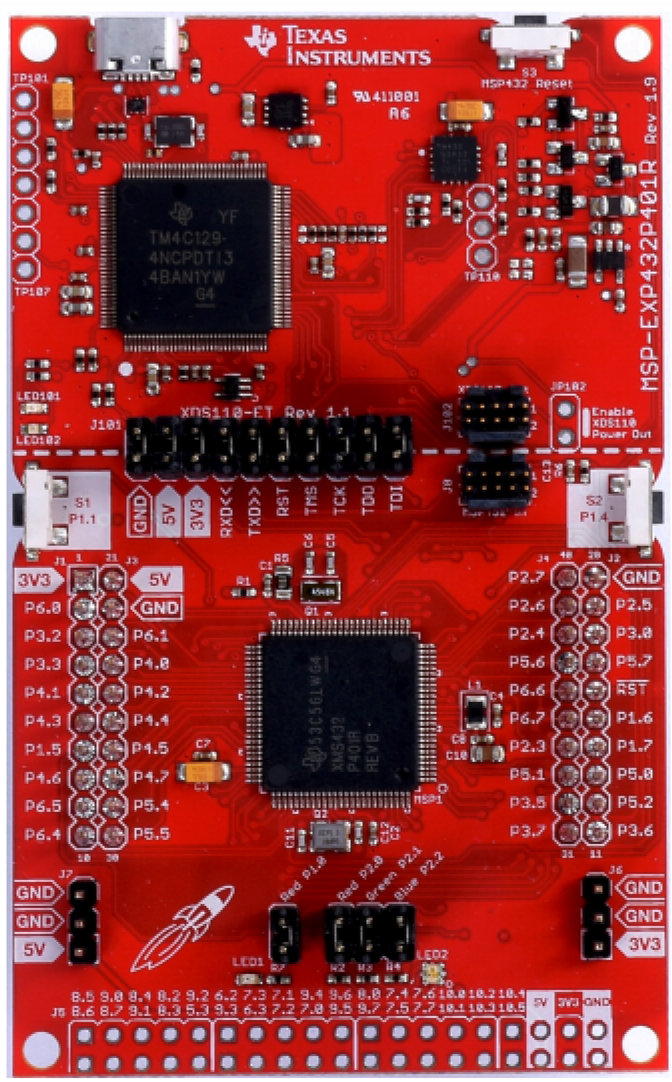


Figure 18: MSP432401R Board

5.5.4.5 Raspberry Pi 4

Raspberry Pi 4 is another excellent option for our project, its the newest version of the raspberry pi microcontroller. What's great about this microcontroller is that it has the same computer shipboard as a pc, but a much smaller pc. We can use the Raspberry Pi 3 as a budget desktop. Projects about machine learning have used raspberry pi because it's an excellent microcontroller for projects about machine learning. The Raspberry Pi 4 has RAM ranging from 2GB to 8GB, with a USB 2, and 3 ports, Micro HDMI ports that support 4K, a USB-C Power Supply, and it also has an Ethernet port. We can use the raspberry pi 4 to receive and transfer data from the drone detection cameras to the machine learning program on the computer through the unannounced LoRa module. We can also use this microcontroller to communicate with the drone detection cameras, both the infrared camera and the standard camera, through UART, SPI, or I2C. The onboard features of the Raspberry Pi 4 include;

- 2GB to 8GB of RAM.
- USB 2, and 3 ports.
- Micro HDMI ports.
- USB-C Power Supply.
- Ethernet port.
- SPI, I2C, and UART Communication.
- Quad core 64-bit ARM-Cortex.

Figure 19: Raspberry Pie 4 Board

5.5.4.6 Microcontroller Selection

The microcontroller we have chosen for our project is the MSP430FR6989. The objective of the microcontroller will be to receive and transfer data from the drone detection cameras to the machine learning program on the computer through the LoRa module. The microcontroller must be able to communicate with the drone detection cameras, both the infrared camera and the standard camera, through UART, SPI, or I2C communication. All the other microcontrollers we discussed in the previous section are very suitable for the DroneX. They all meet the requirements for our project. We decided to use the MSP430FR6989 for our project because it has all the requirements for the DroneX. Unlike the other microcontrollers discussed in the previous section, we all have used the MSP430FR6989 in Embedded Systems labs.

5.6 Solar Power

In this section, we will discuss the different types of solar panels that are being considered for our design. Solar panels were Discovered in the early 19th century, solar panels utilize the photovoltaic effect. Solar panels are utilized by using two semiconducting materials. One layer must have depleted electrons and when exposed to sunlight some photons are absorbed by the semiconductor which excites the electrons causing them to jump from one semiconductor layer to Another. This jump produces a small electric current which when happens in mass makes a usable power source. The most common material to use in solar panels is silicon which is cut and polished into wafers. We will discuss the method by which we measure the efficiency of solar panels. The equation below shows the mathematical equation used for measuring solar panel efficiency.

$$\eta_{\max} = \frac{P_{\max}}{E \cdot A_C} \times 100\%$$

$$P_{\max} = \text{maximum power output (W)}$$

$$E = \text{incident radiation flux } \left(\frac{W}{m^2}\right)$$

$$A_C = \text{area of collector } (m^2)$$

Some of the types of solar panel we are considering, Monocrystalline Solar Panels, Polycrystalline Solar Panels, and Thin Film Solar Panels.

5.6.1 Monocrystalline Solar Panels

Monocrystalline solar panel cells are made from a single crystal of silicon. Having a single crystal gives electrons more room to flow providing greater efficiency providing more power to the load which is the largest advantage of this type of panel. However, this is more difficult to create, making it the more expensive option. This structure also provides more durability enabling the panel to last for years longer than the others. [25]

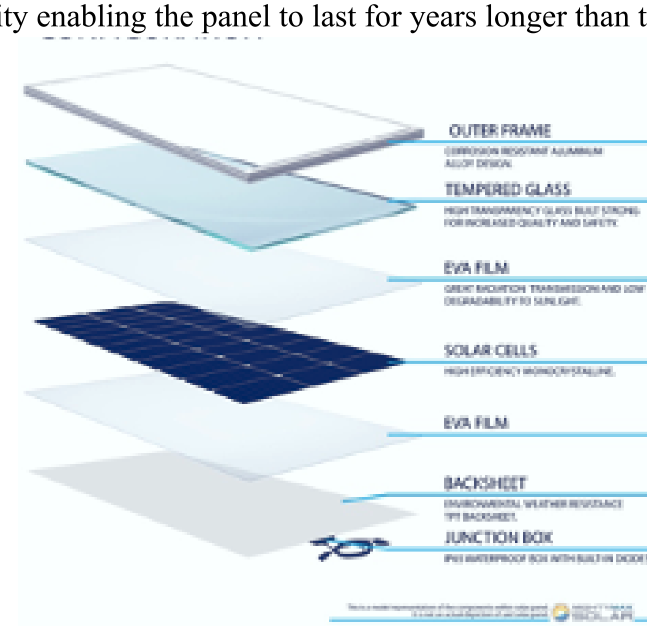


Figure 20 : Monocrystalline solar panel

5.6.2 Polycrystalline Solar Panels

Polycrystalline Solar Panels cells are made from many crystals of silicon. This offers much less freedom of movement for electrons which gives a much higher efficiency. These solar panels are also simpler to build, meaning that costs are lower. This structure also does not provide as much durability as monocrystalline however it does last longer than its thin film solar panels. [25]

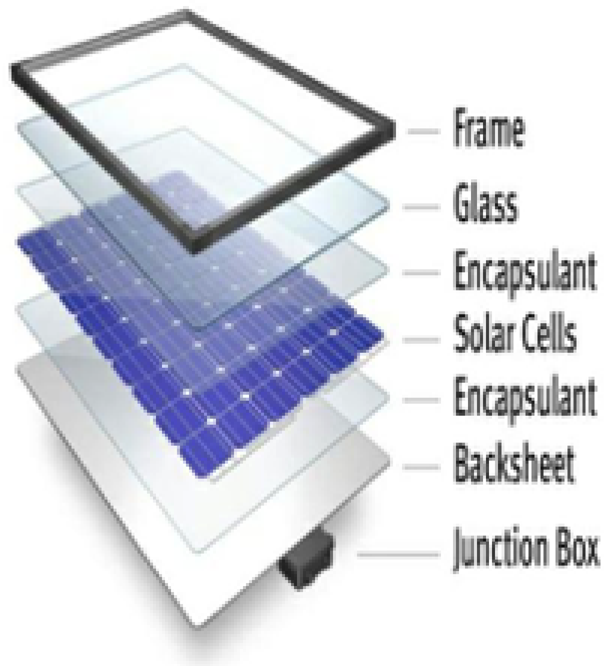


Figure 21: Polycrystalline solar panel

5.6.3 Thin Film Solar Panels

Thin film solar panels are mostly not made of silicon. They are made of a mixture of materials mostly cadmium telluride, which is comprised into a thin sheet between two transparent conductive layers that help capture sunlight. Thin film solar panels usually have the lowest efficiency and durability of all solar panel types however they make up for it in flexibility and where it can be comfortably placed. [24]

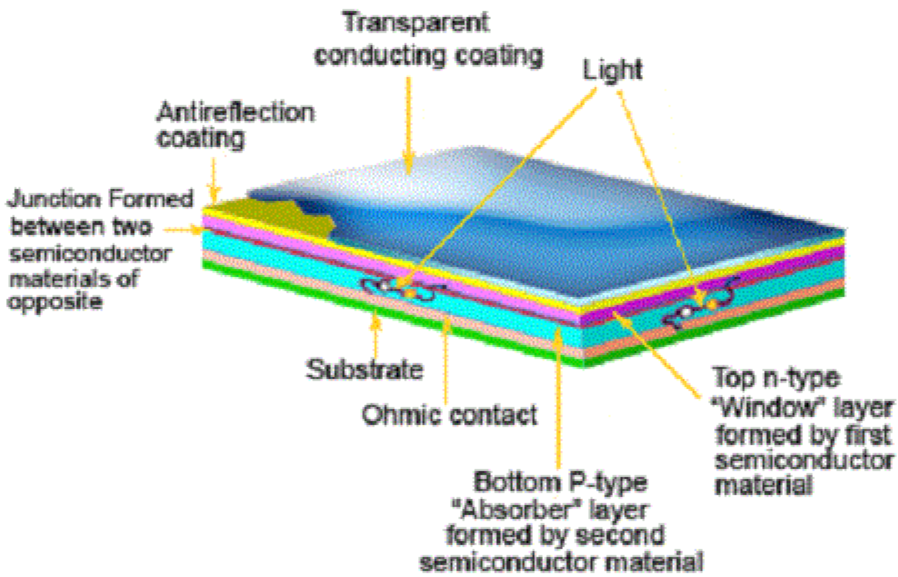


Figure 22: Thin Film solar panel

5.6.4 Solar Panel Decision

The Solar panel that we have chosen is the Monocrystalline Solar Panels because Monocrystalline is more efficient than polycrystalline and thin film solar panels, Monocrystalline is 20 percent more efficient than them. The solar panel we have decided to use is the P105, it's a Monocrystalline 5.5w and 6v solar panel. With this solar panel we should be able to provide our system with a reliable and powerful source of power that can keep the system independently online for a long time. A figure of the P105 solar panel can be found below.

Figure 23: P105 Monocrystalline Solar Panels

5.7 Battery

In this section, we provide an overview of the different types of batteries that we considered using in our design. These types include lithium-ion batteries, and Lead batteries. We're going to talk about each one of these batteries and make a decision on which one to use for our project.

5.7.1 Lithium Batteries

A lithium battery is a positively charged cathode typically made of a lithium oxide metal that will give off lithium ions. Lithium-ion batteries have significantly high energy density, high specific energy and longer cycle life. Lithium-ion batteries have a slow self-discharge rate and a wide range of operating temperatures. More than 50% of the consumer market uses lithium-ion batteries. You can find Lithium Batteries in laptops, mobile phones, cameras, and many others. [23]

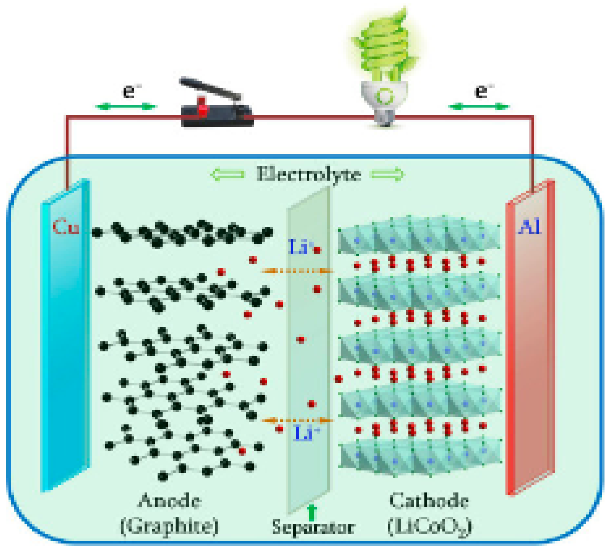


Figure 24: Configuration of a lithium ion battery.

5.7.2 Lead Acid batteries

Lead batteries consist of two electrodes, a negative electrode consisting of lead and a positive electrode consisting of a lead oxide. The two electrodes are submerged in an electrolyte solution comprised of a mixture of water and sulfuric acid. The lead-acid batteries are by far the most popular and most used rechargeable batteries. They have been a successful product for more than a century. Lead-acid batteries are available in several different configurations like small, sealed cells with capacity of 1 Ah to large cells with capacity of 12,000 Ah. Lead acid batteries are mostly use in the automotive industry, other industries such as energy storage, emergency power, electric vehicles (even hybrid vehicles), communication systems, and emergency lighting systems. [22]

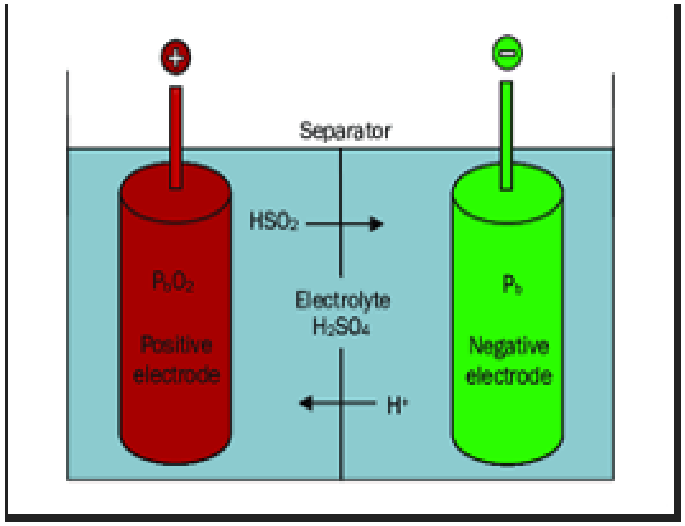


Figure 25: configuration of a lead acid battery

5.7.3 Battery Decision

The battery that we have chosen is the rechargeable 3 cell Lithium-ion batteries. An image of it can be found below. This provides a voltage of 3.7V and 6AH. This means we can expect 22.2WH of capacity allowing our device to run for months without need of ever recharging.

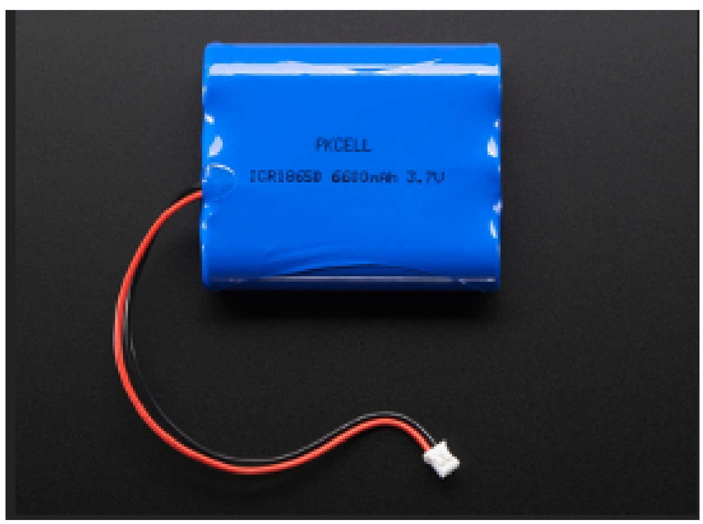


Figure 26: Lithium-ion battery

5.9 Drone Detection using Image Detection and Image Tracking

5.9.1 Introduction

To detect drones we will be utilizing Image Detection alongside Image Tracking. Image detection is responsible for classifying objects in a certain image in our case it is classifying drones. After classifying the drone and identifying its initial position, the Image tracking algorithm will track its movement as long as it is visible and identifiable by the system.

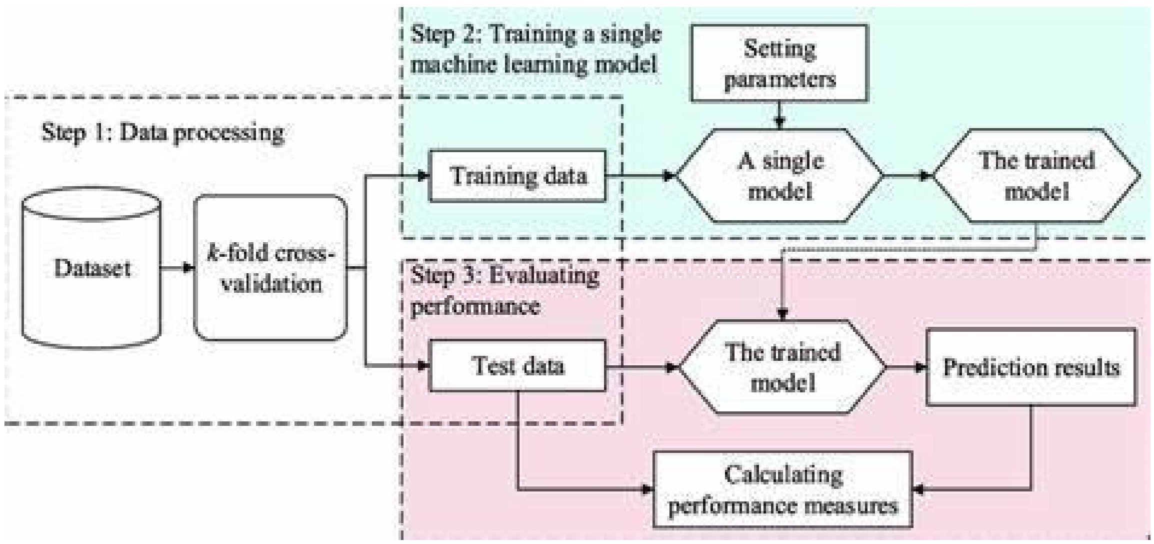


Figure 27: Figure showing the process of building a Machine Learning Algorithm

To build a really good machine learning model, certain steps need to be taken and first, we need to extract the data from the dataset. Then we need to perform preprocessing steps on the data. This includes feature extraction and feature normalization that will help us build an accurate model. The pre-processing steps differ depending on the model and the data we have. After finishing the pre-processing steps, we will split the data into a training set and a testing set. The training set will be used to train the model and the testing set will be used to test the accuracy of the model. After testing the accuracy and the validation of the model we will repeat the process until we have good accuracy depending on the size of our dataset.

The dataset is one of the most essential components in our Image detection and Image Tracking. Another essential issue to keep in mind is that the environment can alter the visual for example on a foggy day the visual may be blurry. Thus drone detection needs a dataset that represents a range of environments, this will enable us to build a drone detection that is able to detect drones in different environments, types, sizes, etc..

Another issue that we will face with using a normal camera is the inability to detect drones in dark or noisy environments. Thus we will also require an infrared camera to assist in detecting drones in a dark or noisy environment. Also we won't be able to only use an IR camera, since details are lost and issues like Drone Vs Bird(discussed in 2.8.2) will not be able to be resolved when using an IR camera only.

Alongside the camera, we will also need a dataset and computer vision system specific for drones captured using an infrared camera. This will require us to have 2 different image processing models, one for the normal camera and one for the IR camera. The system will receive the result from each model alongside the certainty of each model and thus the system will choose the result with a higher certainty. If one of the models detected something that the other one was not able to detect then the result of the system is going to be the result of the working model. This will assist us to have a higher accuracy since each is good at capturing what the other is weak at and the combination of both will assist us in capturing more drones.

5.9.2 Drone VS Bird

An issue we may face after training the model with the dataset focusing on only drones is the misclassification of birds as drones. This issue is not clear whether we will face such an issue or not. However, a study conducted by Seidaliyeva et al. highlighted that due to the high false positives caused by visual similarities that affect drone detection, birds are misclassified as drones and thus need to be taken into account.

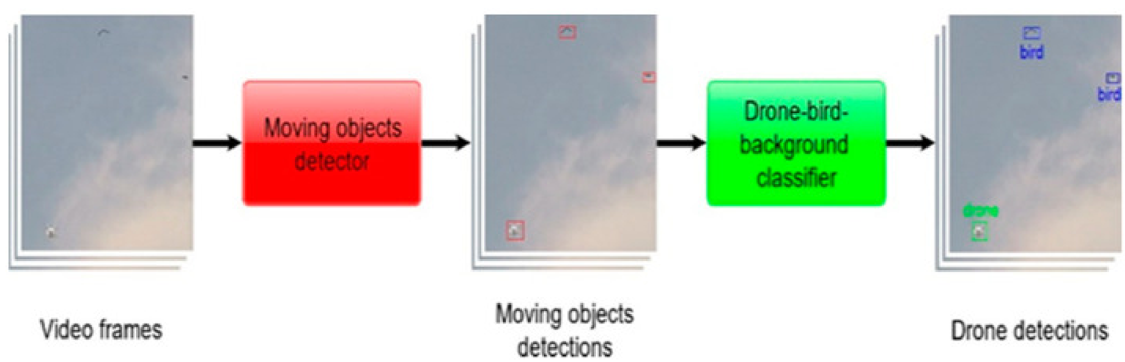


Figure 28: Figure showing a proposed solution to the drone vs bird issue.

The proposed solution for this is to have a moving object detector and a drone-bird-background classifier. The moving object detector will be responsible for detecting any moving object in the image. Then these objects will be passed to the classifier which will be trained to classify drones and birds. This way we avoid the issue of the model misclassifying the bird as a drone since it is trained to detect birds. Thus a dataset that consists of birds and drones will be needed. The motion detector will be using a background subtraction method and the classifier will be a CNN, to be discussed in 5.9.3, trained using a dataset of drones, birds, and backgrounds.

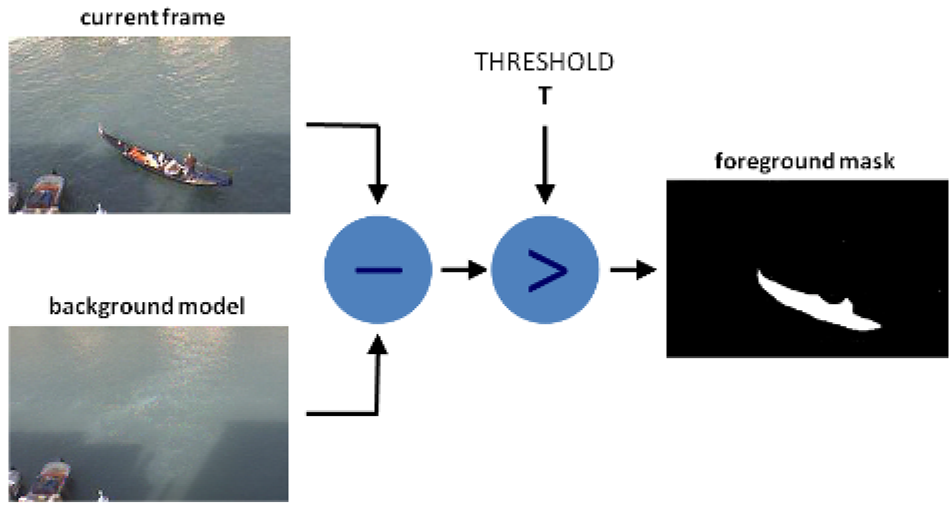


Figure 29: Figure showing the process of background subtraction method

Background subtraction method is a method that is useful for detecting flying objects in a video. Alongside that, it is an efficient, fast, and accurate method of detection, thus making it suitable for real-time detection. To use the background-subtraction method, a static background in the video that will be acquired from the DroneX is required. The reference image/background model will be provided during the setup of the DroneX and updated every few hours as the cloud will be moving, thus detecting movement from the clouds and affecting the results.

Therefore, we require multiple datasets, with each having a unique purpose. Through trial and error, we will identify which dataset or combinations of datasets are the best for our application. One of the main challenges of using multiple datasets is that the data has to be in a similar format. For example, all images have to be the same size. To fix this issue, we will resize the images before feeding them into the model, which will cause some pixels to be deleted or added that could compromise the resulting model and give us an inaccurate model.

Another challenge is the format of the labeling of the data within the dataset; all the data has to be in one format to be able to train the model. This will be achieved by writing scripts responsible for converting the dataset to a specific format. Therefore allowing us to use multiple datasets for the training of the model.

5.9.3 Datasets

5.9.3.1 Real World Object Detection Dataset For Quadcopter Unmanned Aerial Vehicle (UAV)

Figure 30:Figure showing a preview of the Drone Detection Dataset

This dataset is constructed by Maciej Pawełczyk and Marek Wojtyra. The primary motivation of this dataset is to focus more on drone detection than drone tracking. This is achieved through the dataset consisting of 51446 train and 5375 test 640x480 RGB images presenting drones in different sizes, types, positions, scales, environments, and times of day with corresponding XML labels set. The motivation of this dataset is to have it prepared for Haar Cascade training and ANN training, which will be discussed in 5.9.4. These machine learning models are low-power and well-established applications.

5.9.3.2 Multi-view drone tracking datasets

While the previous one focuses on drone/image detection, this dataset focuses on drone/image tracking. The dataset consists of multiple datasets with drones flying captured by multiple consumer-grade cameras (smartphone, etc..) with highly accurate 3D drone trajectory ground truth. This is recorded using a precise real-time RTK system from Fixposition. For each dataset, the number of cameras, the flight duration, velocities, motion types, and the environment varies.

Dataset	3D trajectory	Synchronization	Camera locations	2D labels	3D orientation
1	Yes	No	No	Yes	No
2	Yes	No	No	Yes	No
3	Yes	Yes	Yes	Yes	No
4	Yes	Yes	No	Yes	No
5	Yes	Yes	Yes	No	Yes

Table 7: Figure showing a summary of the features provided in each dataset of the Multi-view drone tracking datasets

For each dataset, the calibration parameters and images for each camera used to construct the dataset.

Figure 31: Figure showing a preview of one of the Multi-view drone tracking datasets

5.9.3.3 Anti-Unmanned Aerial Vehicle (UAV)

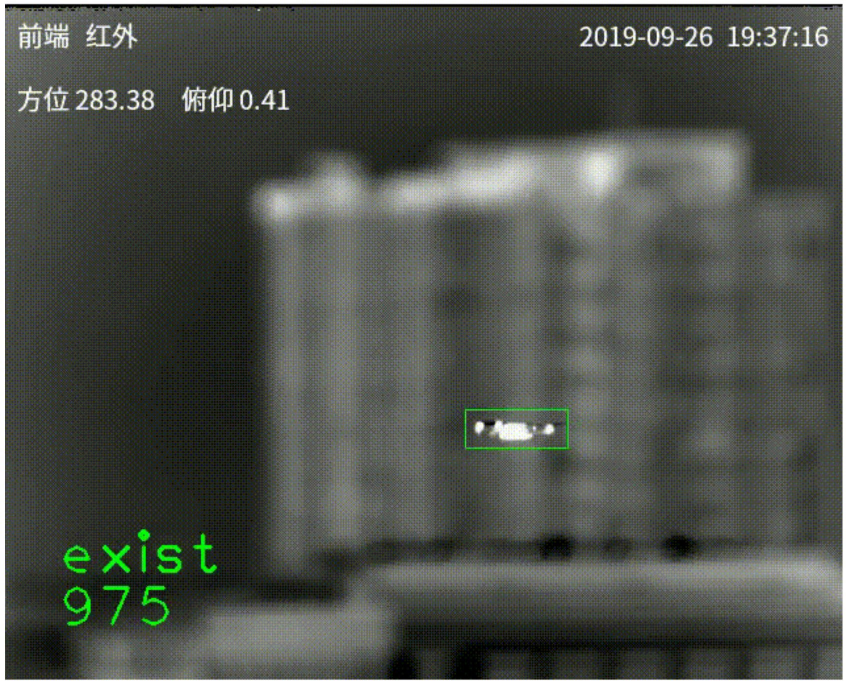


Figure 32:Figure showing a preview of the Anti-UAV dataset

This dataset was constructed by Jian Zhao. Anti-UAV is defined as the recognition, discovery, detection, and tracking of UAVs in the wild and estimating the states of the target given the RGB and/or Thermal Infrared videos. This dataset is different from the other 2 datasets as it also provides Thermal Infrared videos. The primary motivation of this dataset is to provide a high-quality benchmark for anti-UAV. The dataset consists of 160 high-quality, full HD RGB and IR videos with multiple occurrences of different sizes and models of UAVs. The videos are captured using a static ground camera that can rotate automatically or manually by the PC. The drone sizes consist of tiny, normal, and large and the models used are DJI-MarvicPRO, DJI-Phantom4, DJI-Inspire, and DJI-MarvicAir.

Large	Normal	Tiny
		

Figure 33:Figure showing an example of the drone sizes that are in the database.

The data is provided with multiple attributes, bounding boxes, and flags that indicate whether the target is within the frame or not. The list of attributes is tiny, normal, large, day, night, building, cloud, false object, occlusion, hang, scale variation, and speed change.

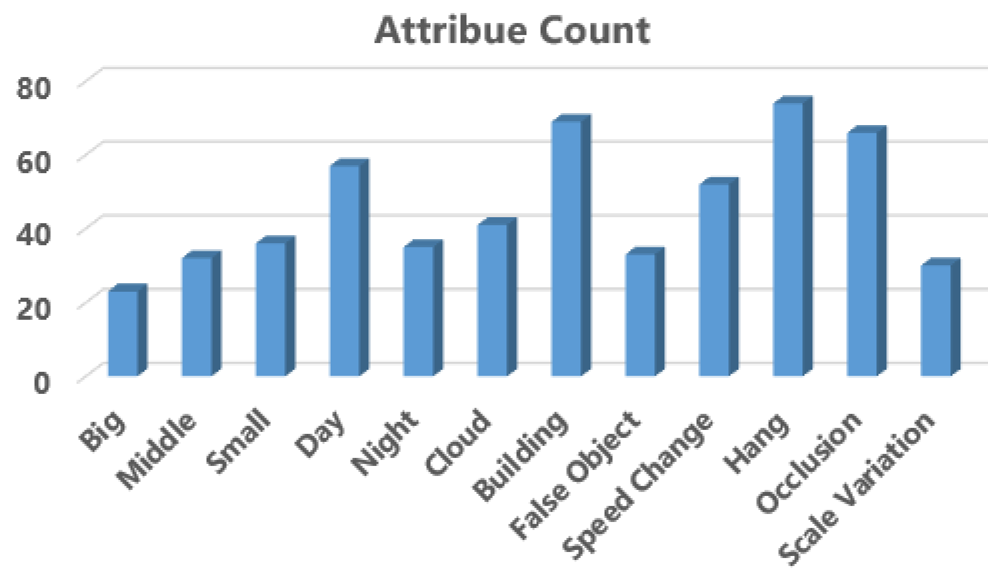


Figure 34:Figure showing a summary of the attributes used in the dataset

5.9.3.4 Drone VS Bird dataset

To deal with the issue regarding the misclassification of drones and birds due to the similarity in shape, we will need a dataset to help us train our classification model to differentiate between birds and drones. To achieve that, we can either build our own or use Amazon Rekognition. Amazon Rekognition provides a predefined model of object detection which includes birds. Thus this service can be used alongside the model that will be built to detect drones.

Figure 35: Figure showing an example of the usage of Amazon Rekognition

To build our own model, we will experiment using the same algorithms we will experiment with for the drone detection algorithm. However, we will need a dataset that focuses on bird detection.

Bird detection and species classification with time‐lapse images around a wind farm dataset

A study conducted by R. Yoshihashi et al. focused on constructing a dataset for bird detection and species classification. This study's aim is to fix the issue of the collision of birds with wind turbines. To resolve this issue, they needed to build a dataset that consists of images of birds in a wide monitoring area, which is perfect for our model, and the label of the species of the birds. In this study, with that data set, they were able to achieve a 0.98 true positive and 0.05 false positive for bird detection using a deep‐learning‐based method in classification.

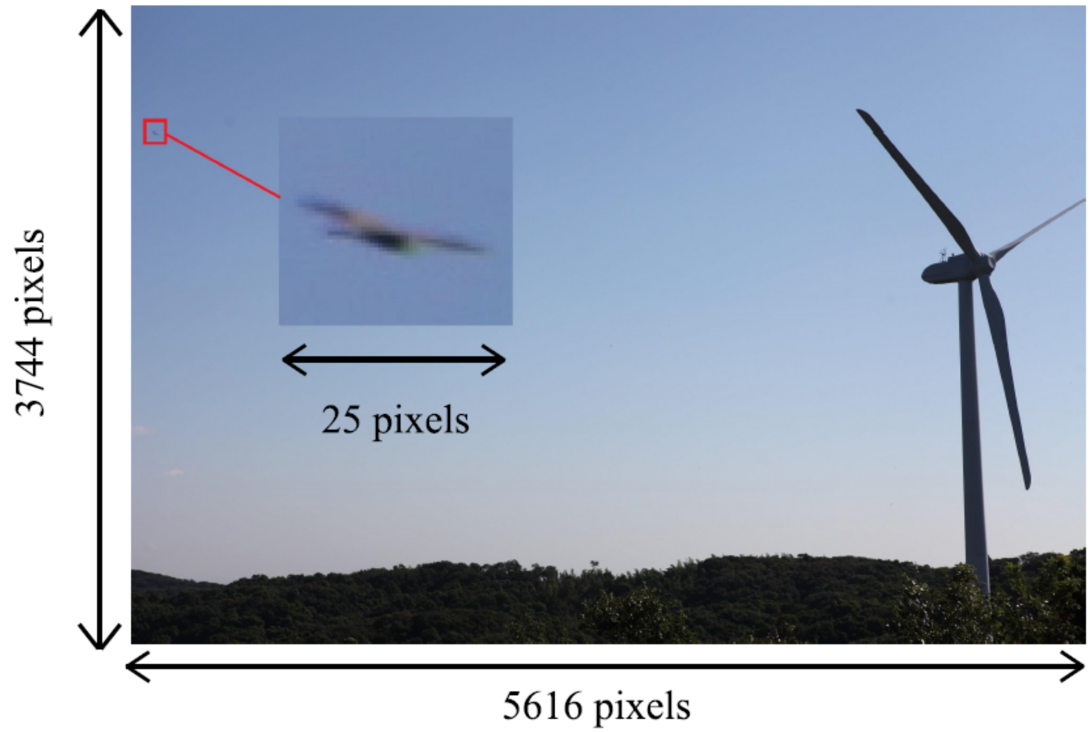


Figure 35: Figure showing an example of the bird dataset.

The dataset consists of 34,442 images that were captured from 9:00 to 16:00. This gives us a good dataset to train our models with. Alongside the bird detection, we can also classify the species of the bird using this dataset since the images are also labeled with species.

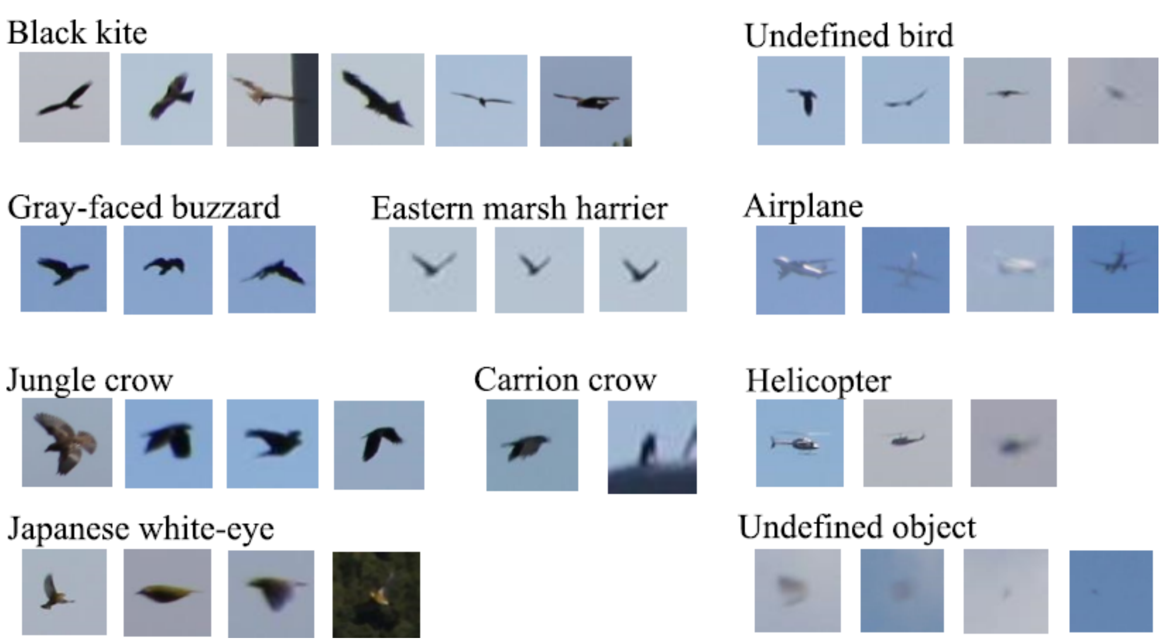


Figure 35: Figure showing samples and their labels of the bird dataset

5.9.4 Approaches for Drone detection and Drone Tracking

There are various algorithms that can be used to detect drones. Each algorithm has its pros and cons. It will be clear which algorithm will be the best for this project after evaluation which is discussed later. Multiple algorithms may be used given that we have 2 inputs, a normal camera, and an IR camera. Thus we will need a model for each and the dataset that will be used to train them will be different. We will have a model responsible for detecting drones using IR cameras and another model for detecting drones using a normal camera. For each model, a different algorithm may be needed. Also, this gives us the option of combining the results of both models and thus could result in higher overall accuracy. We will discuss different options of algorithms that we will use to detect and track drones and the advantages and disadvantages of each algorithm.

5.9.4.1 Haars Cascade for Object Detection

Haars Cascade is an approach in machine learning where multiple “positive” and “negative” images are utilized to train the classifier for object detection. “Positive” images are defined as images that contain the object that we want to detect. “Negative” Images are defined as images of anything that does not contain the object that we want to detect. In our case, “positive” images will contain drones of various sizes, types, environments, and distances. The “negative ” images will contain images that do not have a drone in them.

The algorithm consists of more major steps: Calculating Haar features, creating Integral Images, using Adaboost, and finally implementing Cascading Classifiers.

First, we aim to collect Haar features, which are calculations performed within a detection window on adjacent rectangular regions at a specific location.

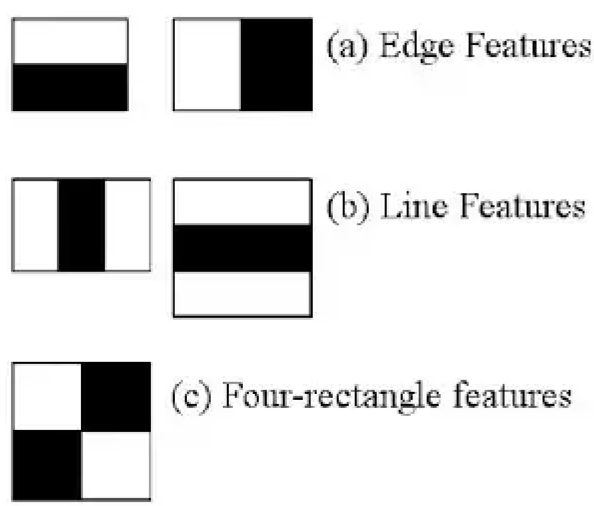


Figure 36:Figure showing types of Haar Features

However for large images, the Haar will be very hard to collect Haar Features. Thus we create Integral Images. Integral images are rectangles of the image that are used for collecting Haar features instead of using every pixel. These Integral images are used to compute Haar features instead of pixels for large images to speed up the process. After having these features, we need to select the best features that represent an object. To accomplish that we use Adaboost Training.

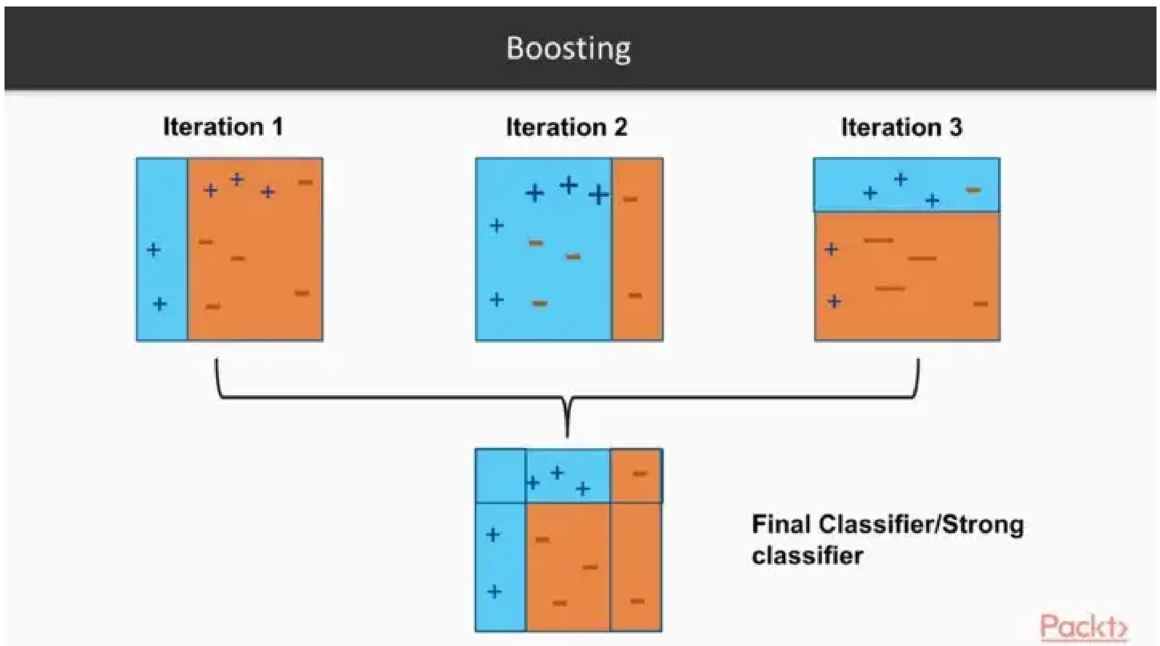


Figure 37:Figure showing boosting algorithms

Adaboost training is aimed to select the best features and then trains the classifier to use these features. It utilizes a set of weak learners/classifiers and combines them to create a strong classifier that can detect objects.

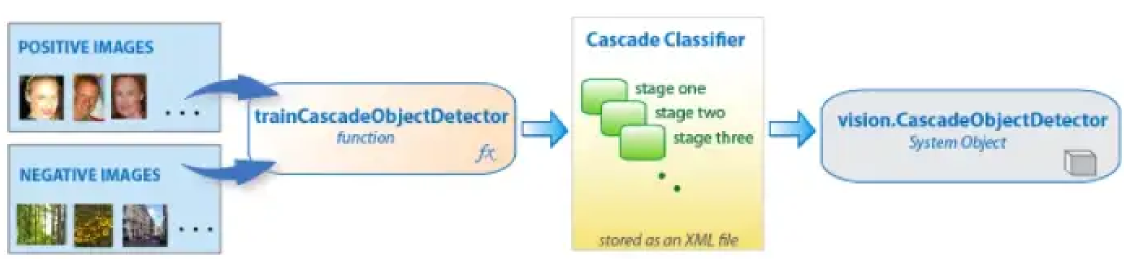


Figure 38: Figure showing flowchart of cascade classifier

Finally after creating the weak learners we combine them using Cascading classifiers. Each stage of the cascade classifier is given a set of weak learners, which are created and trained using Adaboosting which produces a strong prediction. Based on this prediction, the classifier has the decision to either detect an object in this region or move to the next region. Each stage tries to reject a negative sample, which is a region that does not contain a feature or object, as fast as possible. Thus speeding the process of object detection. One of the main points to keep in mind when evaluating and tuning the hyperparameters of this algorithm is to minimize the false negative rate as much as possible.

This algorithm will also enable us to detect drones in real-time due to the use of integral images.

5.9.5 Artificial Neural Networks

Artificial Neural Network is a set of nodes called Neurons, similar to the neurons in the human brain. The ANN is composed of layers of interconnected parameterized neurons. A neuron is defined as a function that classifies the data given and passes it to the appropriate neuron. All neurons are connected using a connection link that is accompanied by a weight, which excites the signal communicating. Each neuron has an Activation signal which is the internal state of the neuron.

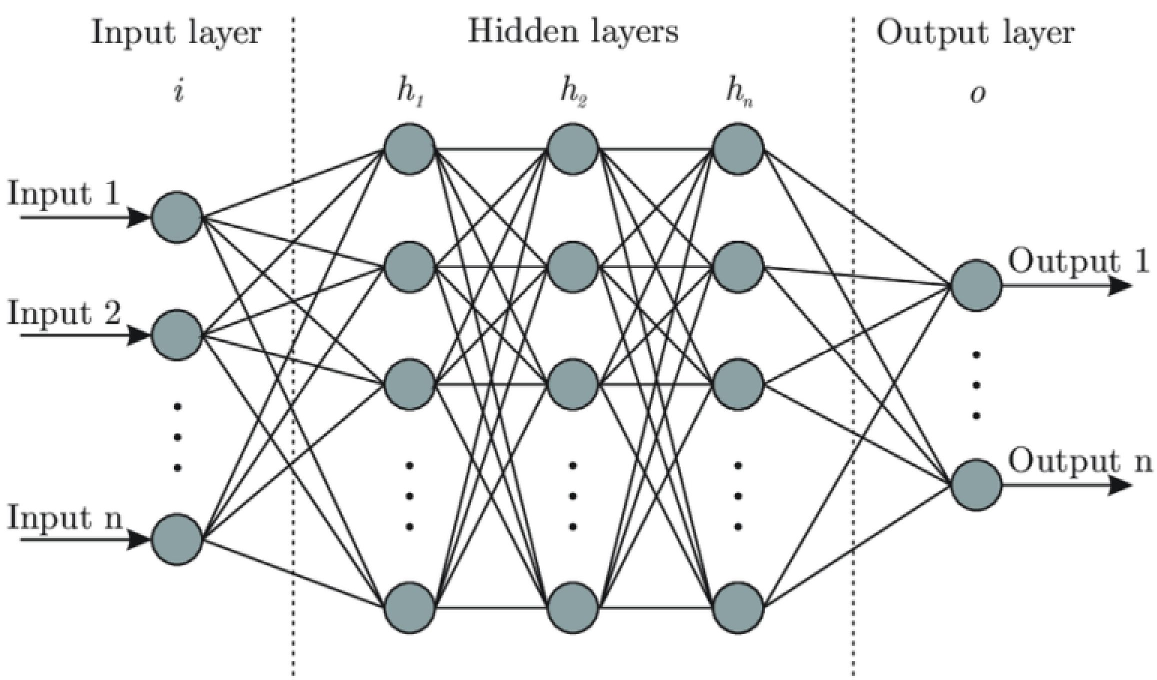


Figure 39: Figure showing the structure of an Artificial Neural Network

An ANN consists of 3 layers, which consist of neurons: Input layer, hidden layers, and output layers. The input layer is the initial layer of the ANN that accepts inputs set by the programmer. The hidden layer is the layer that connects the input layer with the output layer and performs calculations and transformations that will assist in identifying hidden patterns and features. The output layer is the final layer that produces output giving us the result of our application.

One of the major applications of ANN is image processing which is needed for this project. The image is to be transformed into a matrix of color information of the pixels. Each value of the matrix will contain the pixel intensity which is a combination of 3 colors: Red, Green, and Blue.

After converting the image into a matrix, these are the steps to perform image processing using ANN. First image pre-processing is performed which involves noise removal using filters, image enhancement, image smoothening, gray-scale conversion, and image restoration. The pre-processing method will be identified upon implementation to see which is the most beneficial to achieve high accuracy. The output of this process will be an altered version of the input image with the same size as the input.

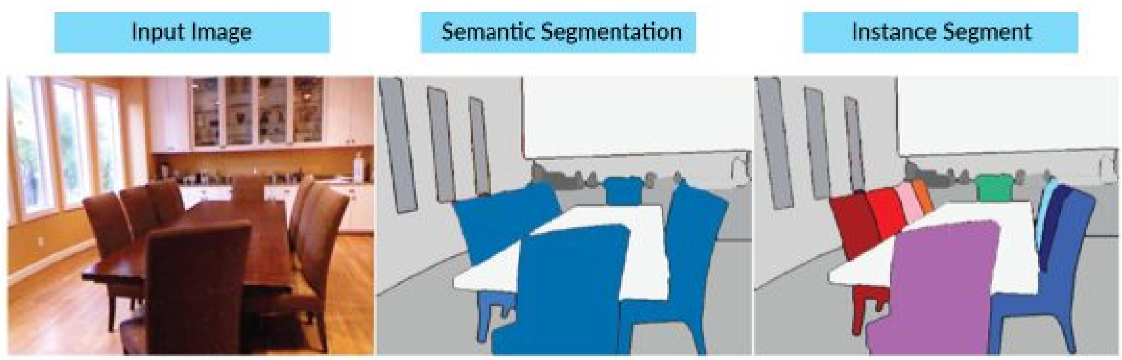


Figure 40: Figure showing the results of different methods of image segmentation

After image preprocessing, we will perform either data reduction or image extraction. Given the image, we want to focus on the part of the image that contains important features. This is accomplished by either image compression or edge detection. After that, we perform segmentation which involves dividing the image into segments depending on the identification of the regions of interest. Finally, we perform the classification of the objects to their corresponding labels.

5.9.6 Convolution Neural Network Image Classification

Like ANN, CNN also contains neurons however the layers are different. CNN consists of 2 main parts, Feature Extraction and Classification. Feature extraction is CNN is accomplished using a set of convolutional and pooling layers. Its aim is to reduce the number of features by creating new features that are representative of the existing features in the original dataset. However, the classification part uses fully connected layers. In CNN, there are 3 different types of layers: pooling, convolutional, and fully connected layers.

A convolutional layer is a layer responsible for extracting features from the input. This is implemented by performing a convolution between the input image and the filter of an odd size (1x1, 3x3, 5x5, 7x7, etc..). The convolution, a mathematical operation, is the dot product of the filter and part of the image with the same size as the filter. This is done over the entire image by sliding the filter over the image. This results in an image/map called a Feature map that contains information like edges and corners in the original image.

A pooling layer is a layer that decreases the size of the image to reduce the computations that need to be done thus resulting in a faster model. The pooling layer is usually set after convolutional layers and also acts as a bridge between the fully-connected layer and the convolutional layer. There are multiple ways for pooling. Max pooling is acquiring the maximum value in the feature map. In Average Pooling, the average is calculated in the image section. Sum Pooling is the total sum of the values in the section.

Finally, the fully connected layer is a layer similar to the hidden layers of ANN. It consists of neurons with weights and biases. This layer is usually positioned before the output layer. The input of the FC layer is a flattened version of the input image after its transformation from the other layers. This is where the classification process takes place.

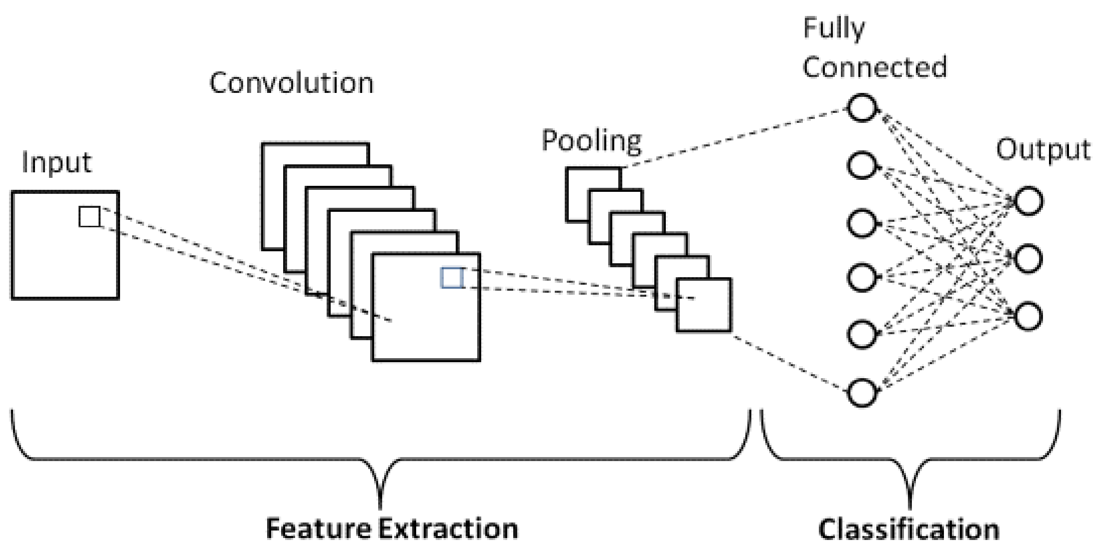


Figure 41: Figure showing the architecture of a CNN

There are multiple CNN architectures each with a specific use and motivation, such as LeNet, AlexNet, VGGNet, GoogLeNet, ResNet, and MobileNet. Each has a different number of layers and parameters. An architecture with a high number of parameters means that will lead to learning more difficult patterns therefore higher accuracy. However, it will require a lot of computation thus requiring larger memory and more time to complete training.

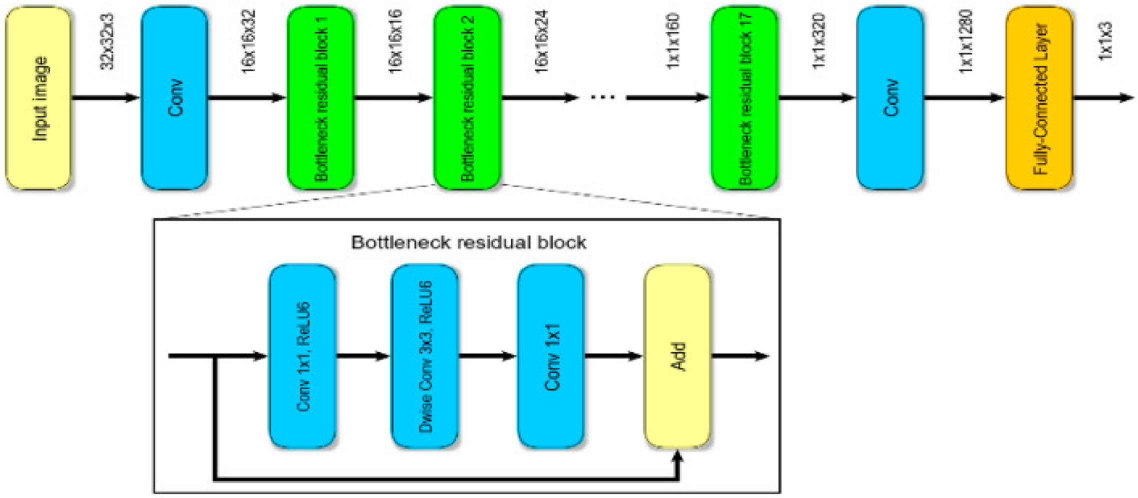


Figure 42: Figure showing the architecture of a MobileNet V2

Given that the video and the image processing will be broadcast from the device to either a mobile app or web app, it will require an efficient CNN with low memory. MobileNet is a convolutional neural network architecture that aims to perform on mobile devices by reducing the amount of memory for computation. MobileNet contains a full convolution layer with 32 filters and 19 original blocks called residual bottleneck layers. After that, a 1x1 convolution layer with average pooling is applied. And finally, the fully-connected layer will allow us to classify the objects.

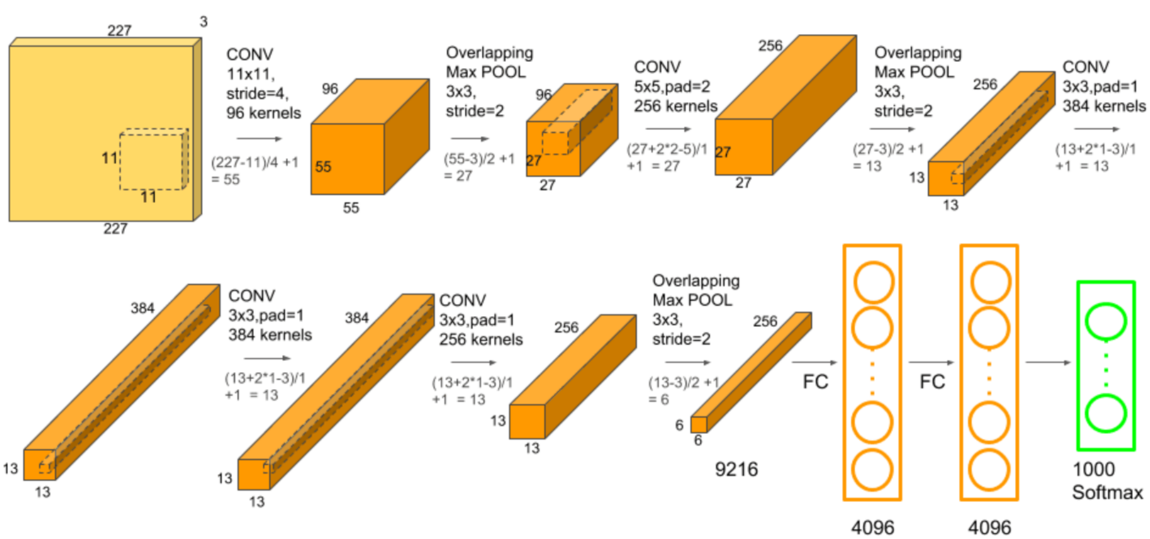


Figure 43: Figure showing the architecture of AlexNet

Another alternative to MobileNet is AlexNet. AlexNet is a popular CNN architecture. It is the first large-scale CNN. It is designed for large-scale image datasets which are suitable for our case. It is composed of 5 convolutional layers alongside a max-pooling layer for each, 3 fully connected layers, and finally 2 dropout layers. Thus resulting in the total number of parameters being around 60 million.

5.9.7 Evaluation

Overall, there are a lot of different algorithms that can be used to tackle this issue and it is unclear which one is the best to use for our model unless we test them. Thus we need measures other than accuracy to test the validity of the model and whether the model is a good fit for our project. Thus we will also track the time taken to train a model and the setup needed to have the model trained. Also, we will calculate the F1 score of the model. It is a measure of the test's accuracy specifically for binary classification models. Also, the metrics in the figure below will be used to further evaluate our model. These metrics are used for multi-model comparison and the model with the lowest AIC, AICc, and BIC are the best.

1. **Akaike's Information Criterion (AIC) by (Akaike 1969) [2]**

$$AIC = n_{train} \cdot \ln\left(\frac{SSE}{n_{train}}\right) + 2 \cdot p$$

2. **Corrected AIC (AICc) by (Hurvich and Tsai, 1989) [3]**

$$AICc = n_{train} \cdot \ln\left(\frac{SSE}{n_{train}}\right) + \frac{(n_{train} + p)}{(1 - \frac{(p+2)}{n_{train}})}$$

3. **Bayesian Information Criterion (BIC) by (Schwarz 1978) [4]**

$$BIC = n_{train} \cdot \ln\left(\frac{SSE}{n_{train}}\right) + p \cdot \ln\left(n_{train}\right)$$

Alongside that, we will also need to keep track of the time it takes for the model to correctly identify the object. Given that real-time detection is to be utilized, thus it is important to have a fast algorithm with high accuracy. However, if for fast algorithms high accuracy was not attainable thus we will have to choose the model that has high accuracy but with a delay caused by the model.

The machine learning system may cause a small delay or overall choppy footage since each image/frame is being processed, and the processing time could be high enough to be noticed by the user. One of the ways to fix this is to have a buffer that saves multiple continuous frames that are already processed in the machine learning models and sends/streams these frames. Thus having smooth footage of the video but with a delay, will result in a better user experience. The number of frames that are needed to be able to stream will be dependent on the processing time of a frame, and the time it takes to detect a drone.

		Actual	
		Positive	Negative
Predicted	Positive	**True Positive**	**False Positive**
	Negative	**False Negative**	**True Negative**

Figure 44: Figure showing the values used to calculate the accuracy, recall, and precision

Accuracy, Precision, and Recall is all evaluation metrics that help identify the model's performance.

Accuracy = (TP+TN)/(TP+FP+FN+TN)

Precision = (TP)/(TP+FP)

Recall = (TP)/(TP+FN)

$$F_1 = 2 * \frac{precision * recall}{precision + recall}$$

Figure 45: Figure showing the values used to F1 score equation

The F1 score is an evaluation metric that calculates the harmonic mean of recall and precision. It varies between 0 and 1.

Another important method of evaluation is the hardware used to perform the image processing training and drone detection. Since there is the possibility of being able to perform it on the phone, thus hardware specification needed to perform this process is important.

Overall all these methods will be used to carefully evaluate the best dataset, model, and device to perform this system. Our main aim is to have high accuracy with real-time detection thus our evaluation and decision will be made to maximize these factors.

5.10 Backend Software Stack

The Backend software stack is the portion of the software that will collect the information from our machine learning algorithms and send it to our end user interface. The backend will also be the portion of the software that the user will directly interface with, as the drone incursion feeds and alerts will be broadcasted using this block of software. The backend portion of the software stack is composed of several parts of which each part will be discussed in greater detail. These parts are; the gateways running LoraWAN Network Servers, a server running on an IoT host provider, and a user interface.

To begin with we will discuss the different LoraWAN Network options. There are two types of networks: private and public.Public networks are open as the name implies to anyone. These public networks supply an area with coverage such that they can use LoraWAN in any given area. The two largest that we will be considering are The Things Network and The Helium Network. Registering to one of the aforementioned networks allows the LoraWAN device to operate. The other option is to connect our device to a private network.

There are two options to consider when using a private network. These are where the LoraWAN Network Servers will be configured. As the LoraWAN Network Servers can be run on the gateway device or on its own cloud server. Having the LoraWAN Network Servers on the gateway device causes the gateway device to have to manage more information about the end devices in its network as well as the network as a whole. While having the LoraWAN Network Servers on the cloud allows the gateway to become a simple access point. Having all Lora packets be sent directly to the cloud allows the gateway to operate at a much lower power as well as at a much lower computational load. However this comes at the cost of a much more complex development cycle as developing a server for the cloud is a challenging task. This is why we will look toward service providers such as AWS and Microsoft Azure to simplify this part of development though this will also increase cost.

5.10.1 Lora Packet Forwarding

Lora packet forwarding is the process of the gateway taking data received from end devices and sending it to the internet. This is a software process that demodulates packets that are received from end devices which then allows for transfers of this data to the internet. There are many possible softwares to use for packet forwarding in Lora when setting up a custom gateway. The original is Semtech UDP Packet Forwarding which was created by the founders of the Lora protocol creators. Due to this most compilers have this packet forwarding type already installed into the Lora device.

5.10.2 LoraWAN Network Servers

Just as our device is connected to our gateway using the LoraWAN protocol, our gateway is connected to the internet using LoraWAN Network Servers. This is the standardized protocol for devices using Lora to connect to the internet. The end devices must be registered to join as all packets sent by unregistered devices are discarded. The device handshake which was previously mentioned in the standard section of this document will be discussed next.

In this handshake IDs are exchanged that identify the device, the join server, and the application/network session. These IDs are used to generate all other keys needed for the transfer of data. With the only key not being transferred being the Appkey as this key will remain stored on both the end device and the network server. Then the network server will need to be able to communicate with an application server such as AWS or Microsoft Azure. The public servers provide the software needed for users to set up their gateways easily. Then once setup anyone with a reception of the device will be able to use the gateway with the correct permissions as discussed before. The two most popular public networks of which we are considering using are both free. However the Helium Network has an extra incentive built into their network as their Network is built into a blockchain and allows the users of said network to mine cryptocurrency for monetary gain. The Things Network, though also free, does not have this extra functionality. Thus in the next section we will look closer at each of these public network options to decide which will better suit our project.

5.10.3 Public LoraWAN Servers

Public LoraWAN servers are a crucial portion of our gateway design to allow us to connect our own gateway to the internet. Using a public server as opposed to private servers will reduce the cost associated with creating our gateway as many of the public networks are free to access. For our project we will be looking at two possible options: the Helium network and The Things Network.

5.10.4 Helium Network

The Helium network as described in the previous paragraph is a LoraWAN server that is publicly accessible. The Helium network was created with the blockchain and crypto currency technology. Thus when a user wants to use the Helium network they are required to create a Helium Hotspot which acts as the actual server from which the network will be accessed. The use of a Hotspot allows the user to also earn the crypto currency HNT that is associated with Helium.[42] This would hopefully incentivize users to create multiple LoraWAN gateways, as this would not only increase the network size but allow the user to earn more of the HNT crypto currency for monetary gain.

To understand more clearly the crypto currency portion of this network and how it works will be the goal of the subsequent paragraph. This blockchain operates by using an algorithm called Proof of Coverage.[39] Proof of Coverage is a scheme in which the hotspot is located and this pinged location is compared to the expected location of the hotspot. This verifies that the hotspot is in the location it says it is. This is continuously verified using the properties of radio frequencies such that hotspot owners are verifiable. The next thing to know of the hotspots has to do with earning of the crypto currency HNT. To understand this we must first know the architecture that is used when the hotspot issues a challenge. A challenge is a contract issued by the blockchain for hotspots to perform. A single hotspot will issue a challenge then the transmitter will receive the challenge and send back a challenge packet to the challenge hotspot. Any close proximity hotspots will act as witnesses. This witness role verifies the correct packets are being sent for the challenge. This allows the user of the hotspot to earn HNT. As they make a percentage of the reward of the challenge based on the role they had in the challenge whether they were the challenger, transmitter, or receiver and how much participation they had in the challenge as a whole.[39] For our current project making extra revenue would be an interesting addition to our project that could theoretically help reduce the total cost of the project. Thus the next section will detail how the network is set up and then go into the functionality of this network for LoraWAN transmission.

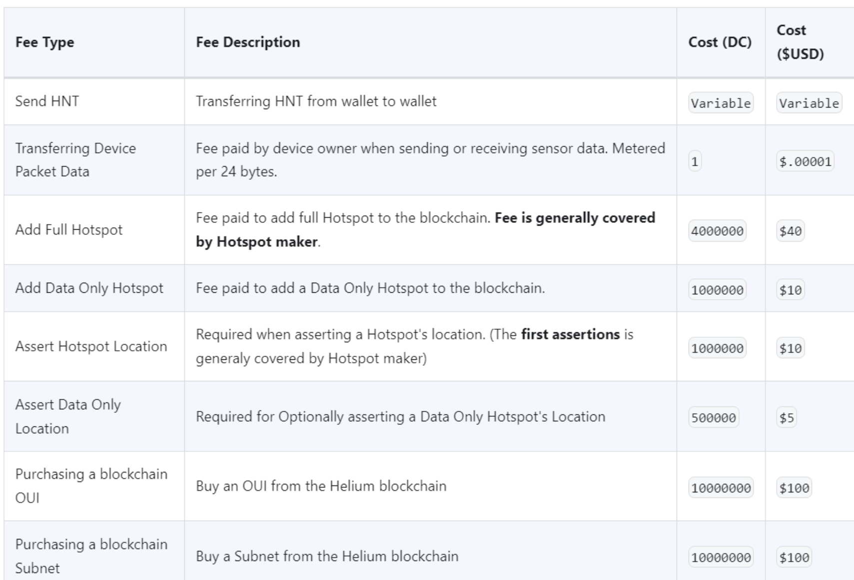
When looking at how to register a device for use on the helium network, such as we would do if we chose this network for our router, we found that there was a simple to follow developer tool. This tool is called the Helium Console. Using the Helium Console the user is required to make an account for the helium platform then add the device that they would like to use as a hotspot using one of its identifiers. These identifiers are the DevEUI, AppEUI, and AppKey or use one of the autogenerated options that were created by the console.[39] Once connected the device is given a unique identifier specifically for helium. Our current router design will be able to connect to this network in its current design as it supports the LoraWAN v1.02 specification.

When connecting our own device there are 3 possible configurations each with a varying level of transmission and HNT earning potential.[42] The first is the Full hotspot. Full hotspots allow for rewards from Proof of Coverage. They also allow for all other rewards that are available from the transmission of packets including as a witness in a challenger packet. The main downside of Full hotspots is that they require the physical device to be manufactured by one of the entities known as makers. Makers are one of several approved manufacturers that helium the entity has decided are equipped and eligible to create hotspot devices. Thus for our own design a Full hotspot would not be viable as we are planning to create our own router rather than purchase one.

The next type of hotspot type is the Light hotspot.[42] The Light hotspot maintains the full functionality of the Full hotspot but does not require a local copy of the blockchain. This decreases the total overhead of Light hotspots making them more energy efficient. This type of hotspot also does not have the added requirement of being made by a maker and is instead available to be set up using the Light hotspot software developed by Helium.

The final type of hotspot type is the data only hotspot.[42] The data only hotspot like the Light and Full hotspots receives rewards based on network data forwarding. It does not however receive any rewards for Proof of Coverage making its potential income much lower than the previous two options. Another thing of note is that this network is consistently being updated and improved. For example as of Q1 of 2023 validators will no longer be used. Validators were a piece of the network system that confirmed the block chain and contracts before adding new blocks to the chain. This function will now have to be performed on the previous types of hotspots discussed.

The last thing to consider with this public network is the block chain fees. Due to this network being made to operate with the blockchain it has several different fees for accessing the block chain in different ways.[42] This includes but is not limited to, transferring HNT, adding a hotspot, and transferring device packet to data. Thus running our device on this network may have more expenses then are worth depending on the profit we could make from using the network.[42]



Fee Type	Fee Description	Cost (DC)	Cost ($USD)
Send HNT	Transferring HNT from wallet to wallet	Variable	Variable
Transferring Device Packet Data	Fee paid by device owner when sending or receiving sensor data. Metered per 24 bytes.	1	$.00001
Add Full Hotspot	Fee paid to add full Hotspot to the blockchain. **Fee is generally covered by Hotspot maker**.	4000000	$40
Add Data Only Hotspot	Fee paid to add a Data Only Hotspot to the blockchain.	1000000	$10
Assert Hotspot Location	Required when asserting a Hotspot's location. (The **first assertions** is generaly covered by Hotspot maker)	1000000	$10
Assert Data Only Location	Required for Optionally asserting a Data Only Hotspot's Location	500000	$5
Purchasing a blockchain OUI	Buy an OUI from the Helium blockchain	10000000	$100
Purchasing a blockchain Subnet	Buy a Subnet from the Helium blockchain	10000000	$100

Figure 46: Shows the varying cost for the Helium network

5.10.5 The Things Network

The Things Network is the other type of public network we are considering. This network uses the LoraWAN stack and is an entirely open source network which allows its instance to be run on any server. This network also has 21,000 total gateways operating though this network is more widely available in Europe than in Florida.[57] The Things Network similar to Helium has a Console which is a tool for configuring devices to become gateways. There are two options when configuring a device for The Things Network. The pre-bought out of the box ready devices have pre configuration options that can easily be found within the Console. This is not the kind of device we are planning however, as we are looking to build our router using a Raspberry Pi 4. Thus we will have to configure our device using the second method. This still uses the Console but we input the identification of our router such as DevEU to register the device.[57] Another important aspect of The Things Network is their suggestions for performance metrics. In the The Things Community Network guidelines they make suggestions specifically on limiting network use, such as limiting data transmission frequency, optimizing message encoding for size, and avoiding confirmed uplink messages. This is done to ensure that no single user is using too much of the network causing other users to be bogged down. This is to be expected for a network that is free to use with options to pay for increased functionality that we should not need for our project.

After looking at both of the aforementioned networks we have decided to go with The Things Network. This is because it is completely free as it doesn't have any association with block chain and the costs there are associated. The Helium Network also currently not in the best light after lying about their partnership with Lime and Salesforce.[43] This could affect their longevity as a service thus The Things Network is the better choice.

5.11 AC8265 Wireless Module

After our cellular module had broke we quickly researched the best way to implement a WiFi module in our design that would be an easy setup and allow us to accomplish our goals without throwing us off course too much. We came across the AC8265 wireless module seen below. The documentation can be found at the following reference [62].

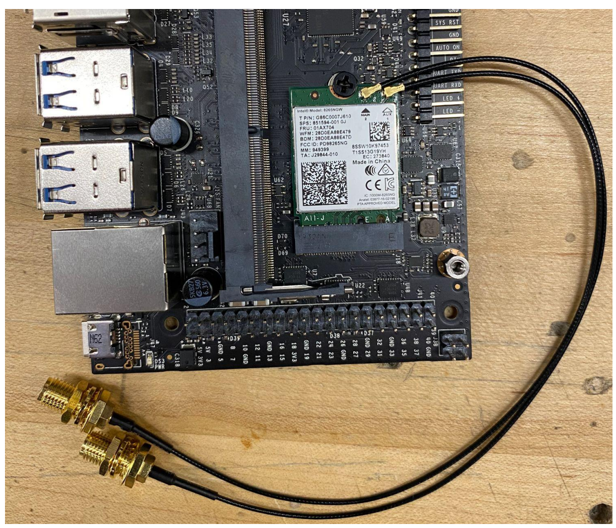


Figure 48:AC8625 Wireless Module

The module was easily implemented, requiring only the removal of the heat sink layer of the Jetson Nano then screwing the wifi module in place. The antenna already came attached so further connections were not required. Once the module was connected the OS on the Jetson Nano already had a working Wifi connection.

6 Design

This section will detail how our hardware will be implemented in our design. Presenting our designs of our power system, and subsystems. These designs will be the implementation of the research that has been conducted in the earlier portions of the document. Showing how the device will be configured through diagrams and pictures of the hardware that we did implement into our design and the reason for these decisions.

6.1 DroneX Case

This section will detail how we designed and implemented our case design for our project. We wanted a case that would protect our fragile electronic components from the elements as best it could. The case would also have to have a clear opening allowing for easy visibility for our camera module as well as several openings such that our two antennas and power cable could be threaded through. With these design constraints in mind we elected to purchase a prefabricated box originally meant to house junctions for a pool or other outdoor switch and modify it to our needs.

The main modifications needed were to drill 3 holes into the side of the case. The first two would be positioned next to each other and be large enough for our antennas to fit through but cut such that we can easily seal the device once we correctly installed the antenna. The next drill hole was on the same side of the box but on the bottom third where we drilled a smaller hole for which our power cable was able to be threaded through with as little free room as possible to limit the chance of water leaking in in the chance that the device were to operate in a rainstorm. We then needed a way to attach all of components such as the PCB and Jetson Nano to the case without having the components move around and potentially damaging each other during a move of the device. To this end we decided to use the conveniently placed bottom cover that was detachable. This bottom cover did not have any structural significance to the case but was a platform for which we could easily attach all of our components excluding the camera. We attached the components down 2 ways for the PCB. We drilled 4 small holes into the platform and placed a small spacer of about an inch on each of the 4 drill holes then placed our PCB on top of that. Screwing down the PCB onto the platform by placing lugnuts on the back and tightening each of the 4 until the PCB would no longer be able to move. The spacers were chosen to be used as it allowed air to flow on both sides of the PCB allowing for cooling to be more efficient. This also allowed for more leeway in terms of size of screws we could purchase as the spacers prevented us from hitting the bottom of the case and allowed for a tight fit such that the PCB would not move.

The next component we put into place was the Jetson Nano. This device came with 4 very small predrilled holes that required screws that were unfortunately not readily available. Thus we instead used 4 zip ties to hold down the Jetson Nano to the platform. This choice was not the most aesthetically pleasing but functionality wise it was the best option we had. We also like in the PCB added 4 spacers to also allow air to flow on both sides of the Jetson Nano to allow for efficient cooling.

The last component we needed to install was the MIPI connected camera. We needed this camera to be as close to the clear lid as possible to limit the potential of glare. Thus to place the camera on the lid we chose to use velcro stickers 2 on the camera and 2 on the lid itself this allowed us to easily place the camera in position for operation and disconnect the camera from the lid if we needed to perform any kind of maintenance on the other components. Several pictures of the finished case design can be seen in the following figures.

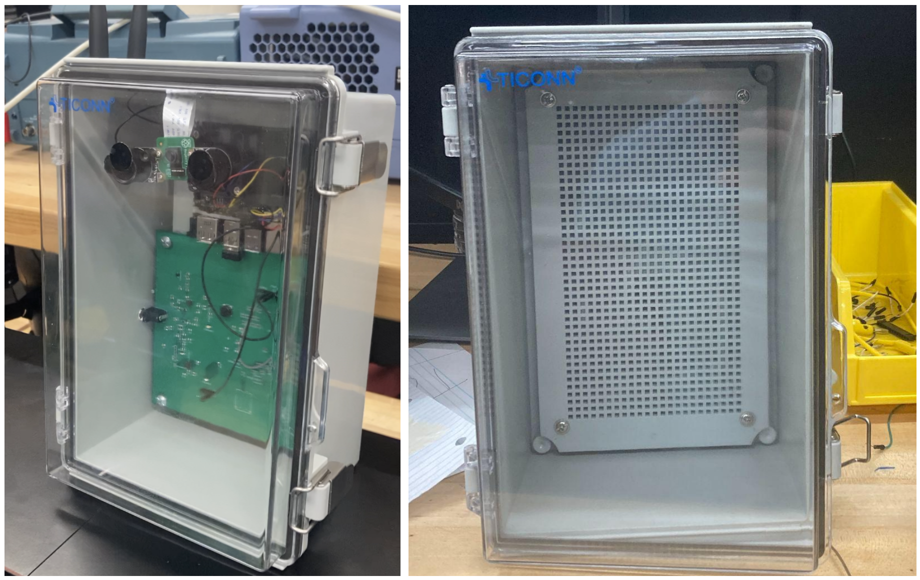


Figure 48: Shows the before and after of case development

6.2 PCB summary

The following figure shows the operational power system used in our design. All of the schematics viewed below have been designed using Eagle as discussed earlier in this documentation. We will show several different components the reason for their inclusion as well as their function. Thus the first figure below is the overall schematic of our PCB.

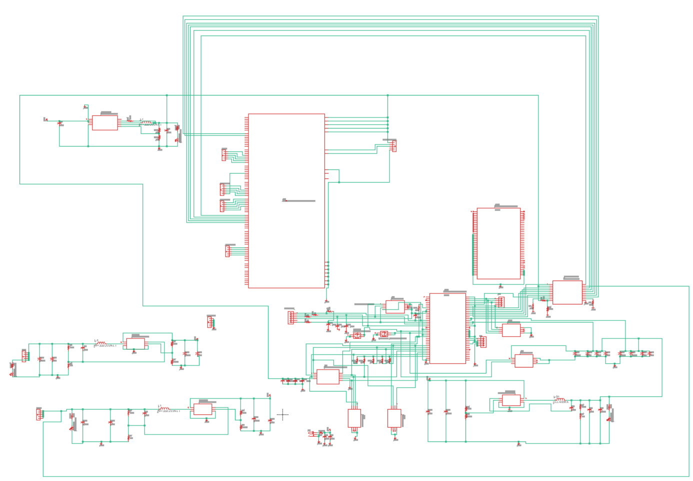


Figure 49: Overall PCB Schematic

6.2.1 Voltage Regulators

The first components of importance for which we will highlight are the several voltage regulators included in our design. We have included two 5 volt regulators, a single 3.3 volt regulator, and a single 3.8 volt regulator. The two 5 volt regulators function in our design was to power the Jetson Nano as well as provide a high voltage for our translator of which we will discuss at a later point. The 3.3 volt regulator was used to power our microcontroller and finally our 3.8 volt regulator was originally used to power our cellular module.

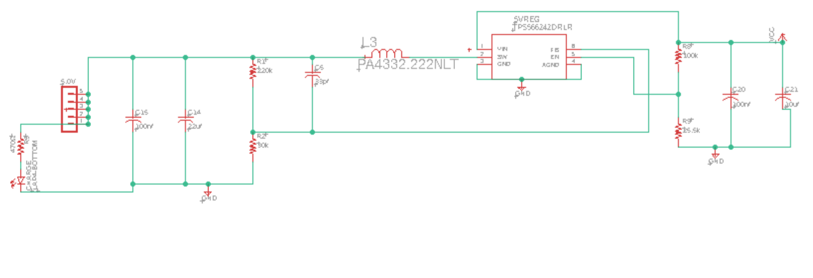


Figure 50: 5 Volt Regulator

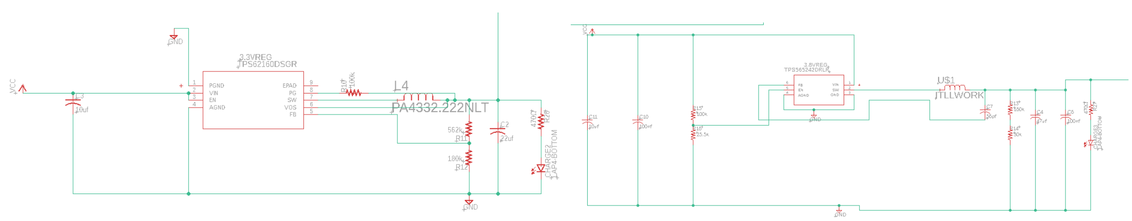


Figure 51: 3.3V and 3.8V Voltage Regulator

Each of the Voltage regulators were designed on a buck regulator foundation. This means that each component though the values differ have a similar function. The first component we will look further into is the selection of capacitors that precede the input of the buck regulators themselves. These capacitors regulate the input voltage into the regulators ensuring that the correct voltage enters the device to maintain functionality. The next components are the inductors of which each allows for an increase in current after the voltage has been regulated due to these all being buck converters the voltage and current will travel through the converter in a feedback loop until the desired output is achieved. This is why we also have the feedback capacitors in the output being fed bac into the regulators it allows a small voltage to be ramped up over many cycles until a desired voltage and current are met. This is the main reason these type of regulators were chosen as for the efficiency of these type of regulators when dealing with multiple input voltage ranges increases the flexibility of the power system as a whole.

6.2.3 Translator

The translator is a component that allows communication over UART between our cellular module the EC25 and our microcontroller the Msp430FR6989. This is necessary as the EC25 module has a 1.8V UART interface which is not compatible with the 3.3V UART interface of the Msp430fr6989. Thus adding the translator to bridge this gap was necessary. It can be seen in its construction that the translator takes both UART connections from the EC25 and Msp430FR6989 as well as this it also has differing voltage inputs one of a high voltage of which we chose to use the output from our 5 volt regulator and a low voltage of which we chose to use the 3.3 volt regulator. When operational the translator takes all UART communication and translates it between the 3.3 volt and 1.8 volt interfaces.

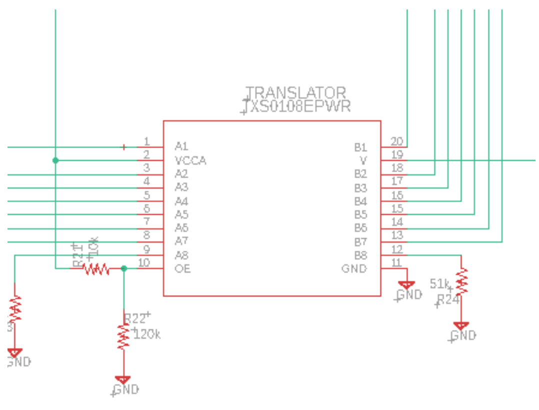


Figure 52: Translator

6.2.4 PCB DC Jack Connector

Our DroneX System is powered using a single DC input jack. This jack allows 6-12 volts to be input into our system. We designed the voltage regulators to each have a 6-12 volt range to increase the ability of our system to be flexible.This allows for many different types of DC input devices to be used to power our system, not just a single wall outlet plug. We also included this range to add battery functionality in the future as many batteries have DC jack connectivity. In the schematic below we have included several decoupling capacitors in our design. A decoupling capacitor's job is to suppress high-frequency noise in power supply signals. They take tiny voltage ripples, which could otherwise be harmful to delicate ICs, out of the voltage supply. The diode included also prevents current from being sent the wrong direction in the circuit.[38]

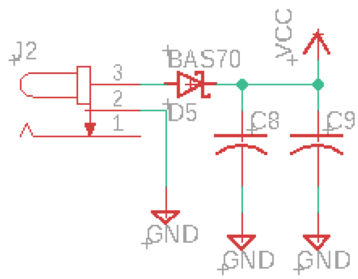


Figure 53: DC Jack Connector

The connector provides a medium for the power to travel to Vcc. The Vcc shown in the figure directly above is the same Vcc shown all over the overall power system schematic. This is the epicenter of the power for the system.

6.2. Cellular Module

The Cellular module has over 140 pins and in Eagle the pinout is separated into 2 sections. Several of these pins are grounded, these pins are: 8-10, 19, 22, 36, 46, 48-54, 56, 72, and finally 85-112. On this cellular module, it required a VDD connection to provide power to the module. The pins 14-17 are connected to the sim card connections. Pins 20, 23, 24 are the reset and power key, both traces are connected to buttons to be able to turn the module on and off as well as reset it if needed. Pins 28-34 are connected to the SD card connections. Pin 49 is the antenna main connection, and the four other connections to the SMA jack are grounded. Pins 57-60 are a power connection, VBAT, a hardware-based power mode that maintains critical operations when a power loss occurs on Vdd.

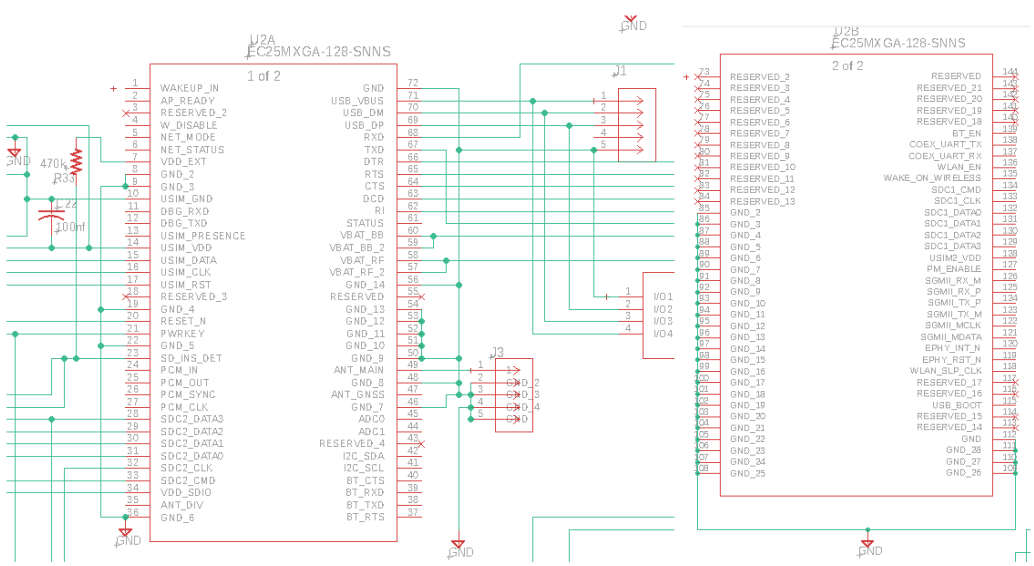


Figure 54: EC25 Schematic

Pin 62 is the RI connection, Ring Indicator is a signal sent from the DCE to the DTE device. It indicates to the terminal device that the cell line is active. Pins 63-68 are receiver and transmitter pins that move data back and forth. Lastly, pins 68-71 are connected to pin headers in case they are needed.

Overall the Cellular Module was the planned method of transmitting data for our system, unfortunately during soldering our module was damaged beyond repair and it was too close to the deadline to order another. Without this component we were unable to provide a system that operates without a wifi connection.

6.2. MCU Connections

The MCU we chose was the MSP430FR6989 this MCU has 100 total pins for which we have made several connections. The first connection of note is from the 3.3 volt regulator output and can be seen connecting to the 5 voltage pins shown in the top right of the schematic. These 5 pins will of course power our MCU but it also leads to the 5 pin header shown to the right of the MCU. This 5 pin header is the dev pin header and includes all the pin connections needed such that we can efficiently flash our MCU. The pins needed for development were pins 28 and 29 as these were the pins needed to flash the MSP430FR6989 the other 2 pins that have a function on the dev pin header is the power line for the MSP430FR6989 and the ground for the MSP4306989.

The next connection of importance are the 2 UART connections made between the MSP430FR6989 and the translator and Jetson Nano. For the translator we were required to have a direct connection to it as it is also present on the board thus we have a trace from the pins 52-56 to the translator to allow for a UART connection to the cellular module. The Jetson Nano required a set of pin headers however because it was not directly present on the board thus we added the UART pin header and connected pins 39-43 to it. Lastly we wanted to make sure we could expand our design in the future and wanted an easy way to prototype new connection ideas such as adding an LED that lit up when a detection was made. To this end we decided to add several I/O pin headers to allow for future prototyping of designs.

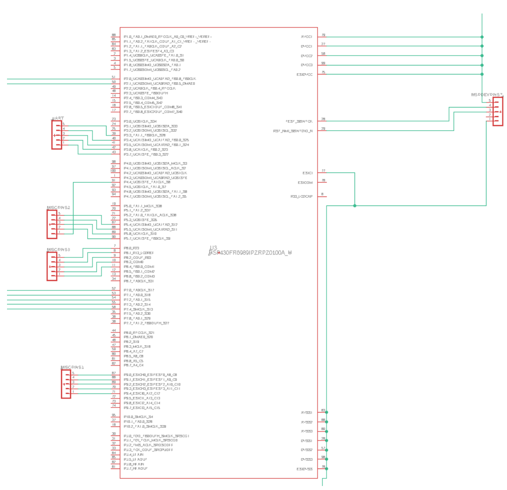


Figure 55: MSP430FR6989 schematic

6.3 Solar Charge Controller

A charge controller or charge regulator is a voltage and/or current regulator to keep batteries from overcharging. It regulates the voltage and current coming from the solar panels going to the battery. If there is no solar charge controller the batteries will be damaged from overcharging. Most 12-volt solar panels put out about 16 to 20 volts. Most batteries need around 14 to 14.5 volts to get fully charged[29].

We originally wanted our system to be a solar battery system and have included alot of documentation for charge controllers below. It was not until we tested the power consumption of our system that we realized that this type of system was not doable for our current project as a battery and solar panel of the size required would be too expensive for the scope of this project.
Lithium-ion solar charge controllers are current and voltage controllers that are used in stand-alone solar systems. The solar panel takes in power from PV arrays and the charger delivers power to the electrical load. The main part of our solar power design system is the stand-alone Li-Ion battery charge management controller. This chip takes in a certain voltage range and can be manipulated to output the desired voltage without drawing too much current from the solar panel. The power that must be considered is the voltage of the microcontroller to be powered, all of the cameras, as well as the solar power output. The charge controller will be responsible for delivering power to the system load and will only draw from the Li-Io battery when more power is needed. By prioritizing available power input over the Li-Io battery, the charge controller can effectively power and charge the system while maximizing battery life. The battery charge controller needed to have dual-input power modes. This is because the power design needs to be able to power and charge the system with a solar panel, also charge and power the system with a USB input. We will provide an overview of the two different types of charge controllers that we considered using in our design. The two charge controller we are considering using; are Texas Instrument's BQ24168 charge controller, and the MCP73871 Charge Controller.

6.3.1 BQ24168 Charge Controller

The first charge controller we are considered for our design is Texas Instrument's BQ24168 2.5A, dual-input, single-cell switched-mode Li-Ion battery charger with power path management and an I2C interface. Our design requires many different things. First, the device must take in different voltages from the solar panels and convert the voltage into a stable DC voltage. Then the device must be able to take in power from a USB source to supplement the needs of the load and battery in cases where a solar panel won't be in use, for example, if the panel is damaged/broken[35].

Another requirement is the IC must have safety protocols that protect and manage battery output and system power management. The BQ24168 IC solves the issue of needing a dual-input charger. It has pins dedicated to taking in both USB and our solar power source, taking in up to 6.5V on the USB side, which exceeds the projected 5V input of the USB. It can also take in 10.5V of an alternative source which fits with the range of the 6V projected input of our selected solar panel. This device also has protections to monitor battery charging current and decreases its input current when the load requires more operational current[35].

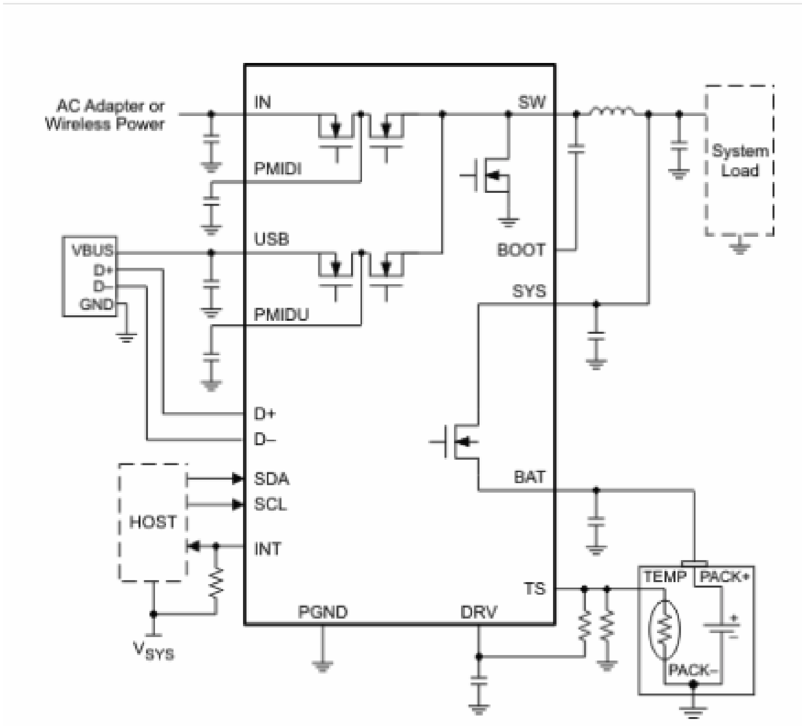


Figure 56: BQ24168 schematic

6.3.2 MCP73871 Charge Controller

The second charge controller we are considering for our design is the MCP73871 battery charge management controller. The MCP73871 chip is equipped with an AC-DC wall adapter and USB port power source selections, satisfying the design requirement for having two main sources available to power and charge the system. The MCP73871 charge controller has an autonomous system load-sharing feature. This feature allows a device to be fully operational while at the same time charging the Li-Io battery. The MCP73871 charger will automatically use any available input power to meet the system load requirement and directly take the input voltage to the output pin. If the input power, solar or USB, does not meet the load requirements, the MCP73871 charger will draw the remaining current requirement from the battery. The VPCC pin on the IC is used to organize the system load requirements over the Li-Io battery charge. Using the VPCC, The MCP73871 charge controller continuously powers the system when the battery is being charged and discharged. The MCP73871 has a transistor inside the chip connected to the load output. This transistor will prevent the loss of efficiency from charging and discharging the Li-Io battery[34].

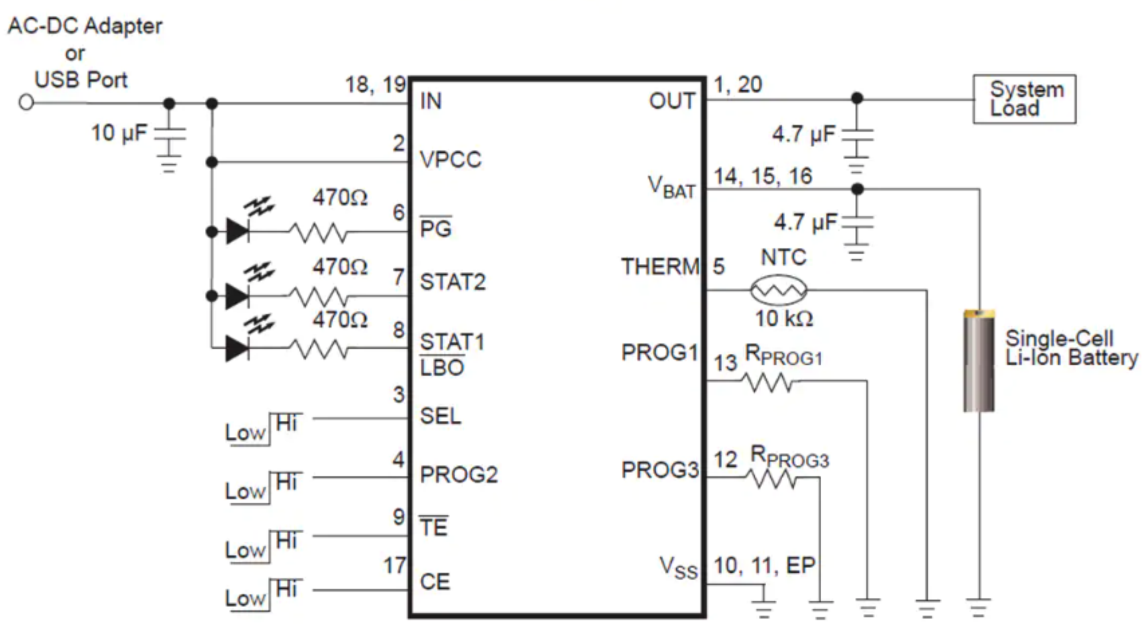


Figure 57: MCP73871 schematic

6.3.3 Charge Controller Chosen for Power System

The MCP73871 Charge Controller was chosen as the best solar/USB-powered option. The decision for which solar/USB charge controller would be used for the power system in the device was between MCP73871 and BQ24168. These two charge controllers were discussed above. These charge controllers have dual-input power lines for operating the system with a solar panel or USB input. Both chargers had built-in circuit protection features and timers that ensured the battery does not get damaged. The BQ24168 and MCP73871 charge controllers have a load-sharing design, where the system can be powered from the input voltage while at the same time charging the battery. These charge controllers were similar in price and other features, and we decided the MCP73871 charge controller was the best option for our project over Texas Instrument's BQ24168.

Charge Controller	MCP73871	BQ24168
input Voltage Range	0.3v - 6v	4.2v - 18v
Max Charge Range	2.5mA - 3.75mA	0mA - 2.5mA
Charge Voltage Range	4.10v/4.2v/4.35v/4.4v	3.5v - 4.44
Fast Charge Rate	100mA – 500mA	550mA - 2500mA
price	$5	$5

Table 8: difference between two charge controller

Figure 58: MCP73871 board

6.4 Power System

This section will look at the power design that will power up the DroneX. The DroneX will have a solar panel capable of powering the system while also charging the Lithium-Ion battery that will be used if the load demand exceeds the capabilities of the solar panel. Additionally, the system will be equipped with a USB port to charge the battery and power the system as a second option. This gives us the design and the flexibility to set a consumed battery and maintain the system directly operating when the solar panel cannot provide sufficient power. A battery charge management controller will be responsible for a voltage-proportional charge control feature that will optimize the solar cell and allow the USB input to power the system.

6.4.1 Power Features of DroneX

A Lithium-ion battery will be the primary battery source in our power system design. The design has automatic charging current tracking through the battery charge management controller IC. This will allow the system to operate at high efficiencies with solar panels of varying wattages.

The charge controller outputs a maximum charge rate and can be adjusted from 50 mA to a 1A charge rate. Our system will draw currents from the solar panel depending on the maximum charge rate to meet load requirements. If the load requires more current, it will receive current from the battery. It prevents the battery from frequently charging and discharging and extends battery life. The DroneX will mostly use outdoors, so the battery temperature was also a part of the design. The battery temperature can be, at most, a specific limit. If it does exceed, then charging it would be dangerous. We would have to add an NTC thermistor resistor connected to the charge controller IC to monitor battery temperature and automatically stop charging the battery if certain temperature thresholds are met.

6.4.2 Solar Panel Charging

The DroneX will use a 6 V solar panel to charge and power the system. We will use a DC jack input to connect the solar panel to the system. Charging the system with a solar panel means a filtering capacitor will be needed to stabilize the solar panel.

Solar panel's voltages and currents vary. The instability of solar panels can cause issues with battery chargers as they continuously turn on and off while trying to draw current from the solar panel, which causes the voltage to drop. When the current increases, the voltage will begin dropping to 0 volts. when the light changes, the battery charger requires more current from the panel, causing the voltage to collapse and the charger to turn off. We will have a charger capable of monitoring the voltage of the solar panel so that it does not demand current past the solar panel short circuit current is needed. With the right charger, we can achieve the right optimization for the solar panel.

6.4.3 Power Schematic

The DroneX Power Schematic will include the charge controller. The heart of this power system design is the solar/USB charge controller MCP73871. One of the concerns with designing a solar-powered system is preventing the voltage from collapsing when there is a high current draw from the load. A charger is needed that is capable of monitoring the solar panel voltage and ensuring demand stops when the voltage begins to drop. This will prevent the battery from constantly charging and discharging.

Pins 6, 7, and 8 on the MCP73871 controller are used as system status lines. We will connect LEDs and resistors to these pins which will indicate either a low battery output, a fully charged state or a power-on state. pins 3, 4, 9, and 17 are the pins that are connected to power. PROG1 pin on the chip layout is used to determine the charge rate of the controller.

6.5 Software Design Summary

Due to time constraints, it will be unrealistic for the software to be implemented after the DroneX is built since the software is highly dependable on it. Thus the machine learning system will be implemented using the mobile as its means of capturing images to test the ML system.

Mobile is a good representative of the DroneX since it has a high-resolution camera and is very portable. Thus this system will be implemented on a mobile device and will be tested and ready for the DroneX to be integrated into the system when it is ready. Therefore it will give the user the option of either using the mobile device's camera to detect drones or connecting to the cloud able to retrieve real-time footage of the DroneX in both standard and IR modes alongside any notification regarding drone detection.

6.5.1 High-Level Design

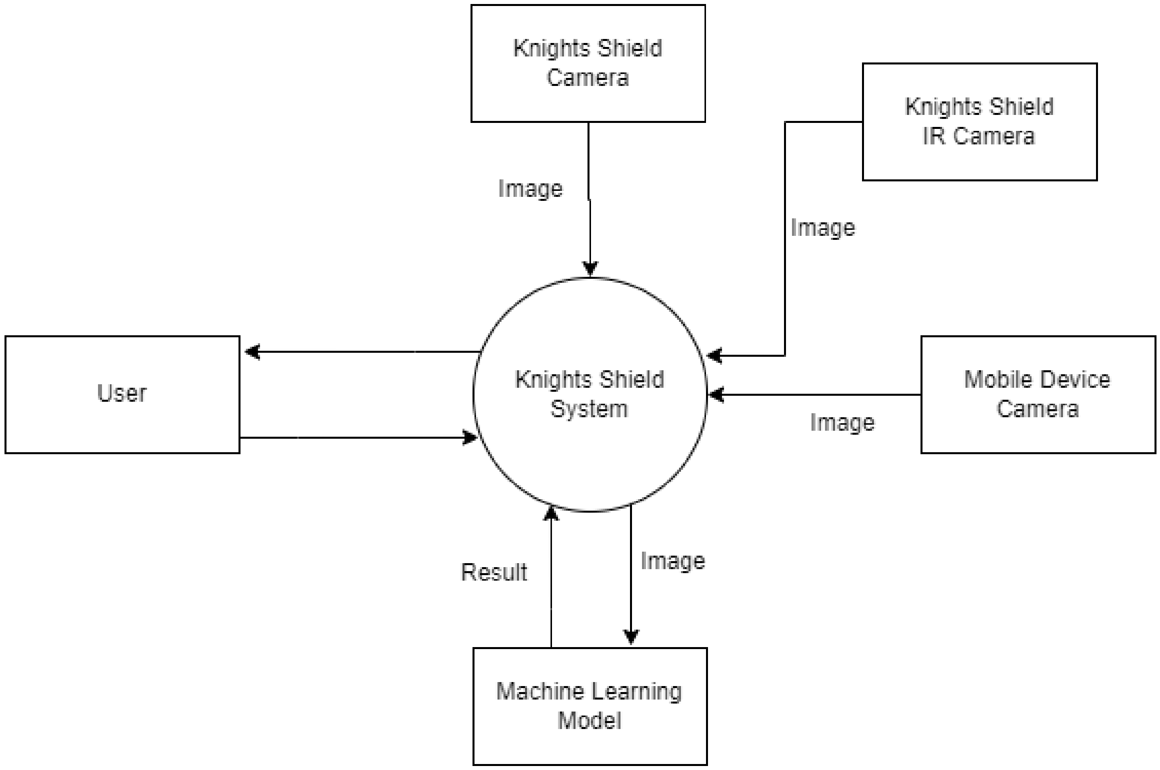


Figure 59: Figure showing the Context Diagram of the DroneX System (formally known as Knight Shield)

The user will have access to the system and will be given the option to either use the mobile or the DroneX. Upon selection, the system will retrieve the appropriate data from the camera selected and the data from the model after using image processing on it to detect whether a drone is visible or not. The user interface is either going to a mobile application or a web application; this depends on the machine learning algorithms requirements that satisfy real-time detection and high accuracy. The system will retrieve the images from the cameras and feed them into the machine-learning model. The machine learning model will send to the user the image and the objects detected in the image alongside their position in the image.

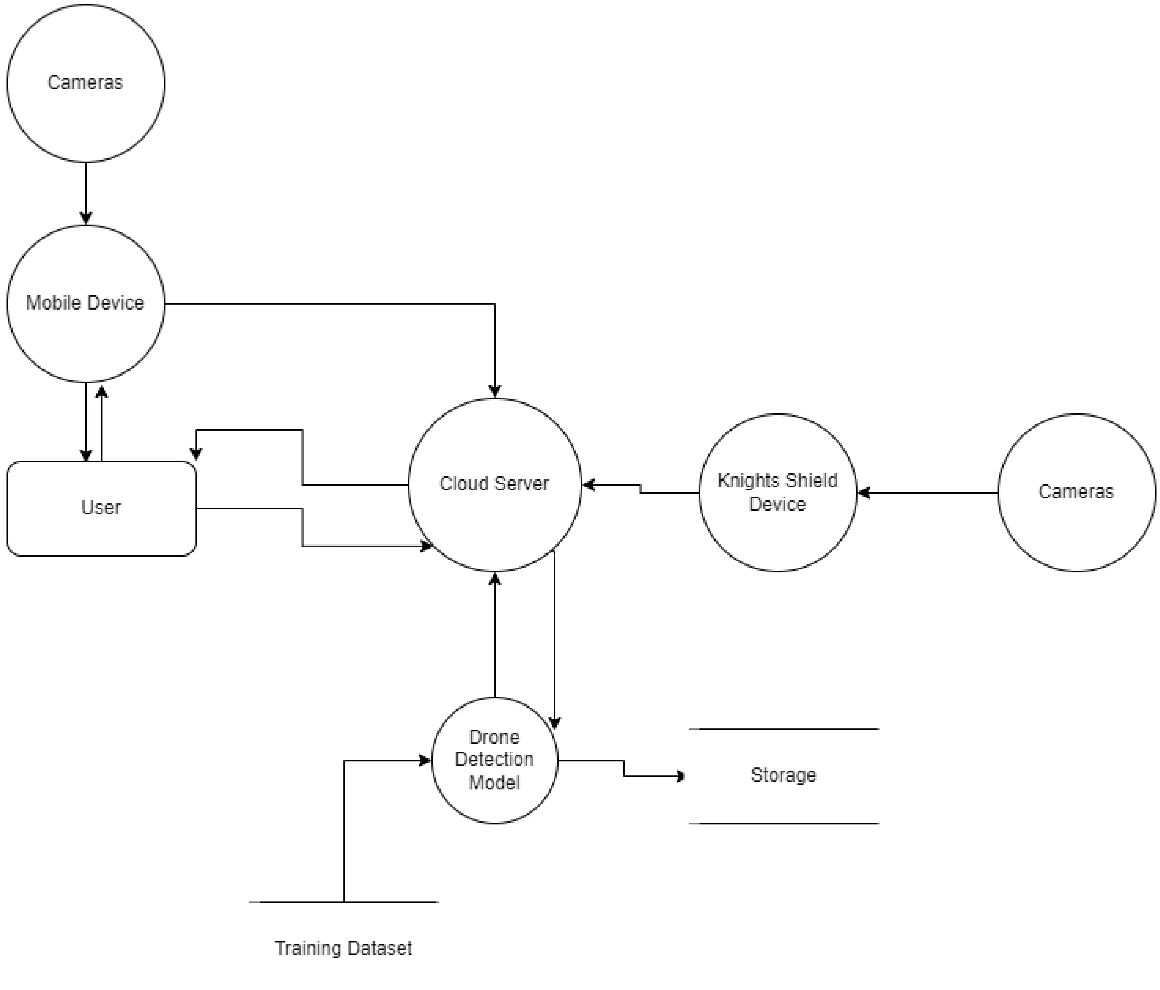


Figure 60: Figure showing the Data Flow Diagram of the DroneX System

The user requests to either use the mobile device for drone detection or the KnightsShield device. If the user chooses the KnightsShield device, the user will receive the necessary data from the cloud. The server will first retrieve the data from the KnightsShield device, which are images retrieved from both the IR and normal camera. Upon retrieval, the device will send the data back to the cloud server. The data will be fed by the server to the Drone Detection Model, and the results will be first sent back and also stored in the storage. The data is stored to keep track of all the drones detected, the time of detection, and their location. After the server receives the results from the Drone Detection Model, the data will be sent back to the user displaying if a drone is detected.

If the user decides to choose a mobile device, instead of retrieving the images from the IR and normal camera from the DroneX device, it will receive them from the mobile camera. However, depending on the evaluation done for the ML, MobileNet is a good model and requires low computational power. If the MobileNet or a fast drone detection alternative is selected, then the image processing and drone detection will be performed on the mobile device, and the result will be sent back to the user. However, if another model is selected, then the mobile application will send a request to the server alongside the images captured. The server will then send the images to the Drone Detection Model and will return the result of the modal to the server and then to the mobile app. Thus showing the users of drones captured by the phone.

6.5.2 Machine Learning

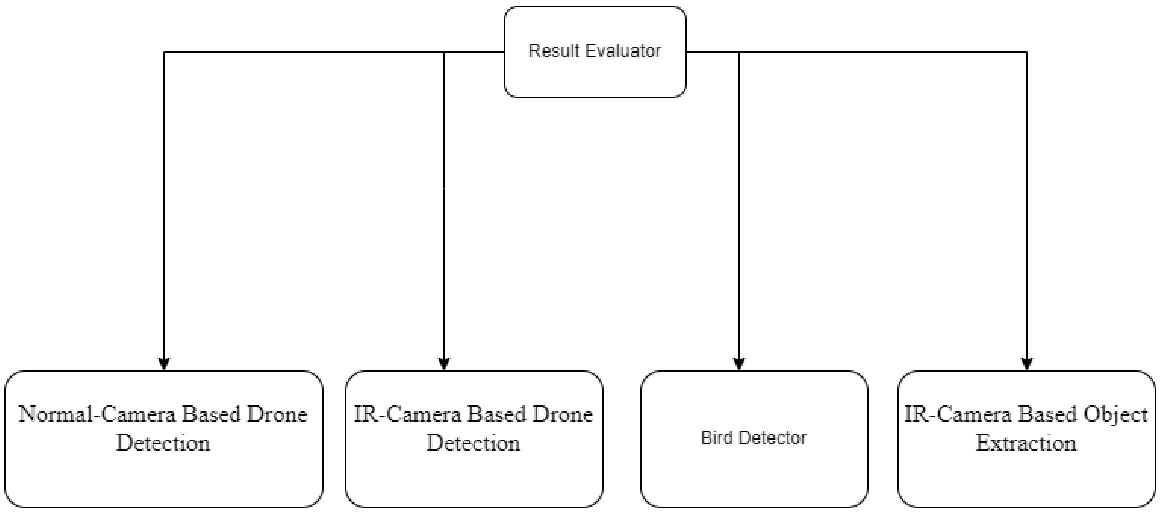


Figure 61: Figure showing an overview of our machine learning system

Normal-Camera-Based Drone Detection

This model is responsible for detecting drones using the normal camera. The purpose of this model is to try to capture and detect drones during daylight. There are multiple datasets to choose from to train the model. We will experiment with which dataset or combination of datasets is the best for training the model.

IR-Camera-Based Drone Detection

This model is responsible for detecting drones using the IR camera. The purpose of this model is the ability to capture drones first at night or in a noisy environment. The second is to assist the Normal-Camera Based Drone Detection by detecting drones and focusing on objects that are captured by IR. On a cloudy day, Normal-Camera Based Drone Detection will output wrong detections as it will assume part of the cloud is a flying object and could classify the clouds as a drone.

This model can either be used for object detection and then the resulting images to be passed to Normal-Camera Based Drone Detection and bird Detection or we can train the model to detect drones captured using IR cameras. The model will be trained using the data compromising of drones captured using the IR camera. It is unclear which will be a better model for our project unless we test it. The first option will assist the Normal-Camera Based Drone Detection to perform better in noisy environments but not dark environments. On the other hand, the second will allow us to detect drones in the dark. Thus both are needed for our application.

IR-based object extractor

This is a module that will be responsible for detecting objects visible through the IR camera. It will output the positions of the objects that are detected in the IR image that has an object. The purpose of this is to assist Normal-Camera Based Drone Detection by identifying the objects that are important to investigate. Any object, for example, leaves or clouds, that is not captured by the IR camera is not going to be a drone or a bird. Upon extracting IR-radiating objects. The module will provide closeup images of the object from the IR image and normal camera image; given the location from the IR camera, it will be in the same position as the normal camera image. These close-ups images will assist the machine learning system in detecting better.

It is still unclear whether this module is useful. It depends on multiple factors. The main one is the quality of the camera. If the quality of the images captured is bad, any close-up will result in a worse resolution, thus making it difficult for the machine learning system to detect any object. One of the ways to fix this is to apply a deep learning algorithm that increases the resolution of the image close-up. This algorithm is called Image Super-Resolution. The aim of this resolution is to construct a high-resolution image from a low-resolution image. There are multiple ways of implementing it but we will have to rule out supervised ones since we do not have data.

Bird Detection

This module will be responsible for detecting birds. Due to the issue of the similarity between drones and birds that exists, thus we need a model that will be able to differentiate between them. To build this model, we can either build our own model or use a pre-trained model. AWS provides Amazon Rekognition which provides pre-trained models for image processing of multiple objects, including birds.

Result Evaluator

Each model in our machine learning system has a purpose. Thus, it is best to utilize all of the models to get an accurate system that is able to perform in various different environments. Given the environment and the result provided by the models, the Result Evaluator is responsible for setting weights and bais to each model depending on the environment. The weighted results are combined to help the evaluator come to a decision regarding the detection.

If the environment is dark, then any results provided by the Normal-Camera Based Drone Detection and Bird detector are near useless. Thus the weight for the Normal-Camera Based Drone Detection and Bird detector is set to 0. Thus only focusing on IR-Camera Based Drone Detection.

If the environment is cloudy, IR-Camera Based object extractor is first needed to correctly identify the objects that are relevant to be classified by Normal-Camera Based Drone Detection.

If the environment is clear, then a combination of both Normal-Camera Based Drone Detection and bird detector will be needed to detect drones in the area.

If both Normal-Camera Based Drone Detection and bird detector have a high percentage of certainty that the flying object is a bird, then it depends on which has a higher testing accuracy. Thus the model with higher testing accuracy has the priority to classify the object.

Overall, the weights of the models are dependent on multiple things, including environment, time of the day, weather, brightness, and a majority vote of the algorithms. The weights will have to be updated continuously during the day to utilize the best accuracy from the result evaluator. An example of why this is needed is the weight of the normal-camera-based drone detection, and IR-camera-based drone detection should be dependent on the brightness. If it is dark, the IR-camera-based drone detection's weight should be much higher than the normal-camera-based drone detection's weight

Deployment of ML System

There are a lot of options for where to deploy the machine learning model. It depends on the minimum resources the model needs to be able to run and detect and classify drones in real-time with the best accuracy possible. This depends on the best model that passes the tests set to measure accuracy, time, and resource, which is discussed in section 5.9. Each option has a different method of deployment.

Mobile

In order to be able to finish and accomplish the project given the time constraint, we will use the mobile to mimic the KnightsShield until it is ready for use. This gives the option of deploying the machine learning system on the mobile itself. If that is the case, we will have to use MobileNet in most of the machine learning models, which have proven to provide fast computation and use low computational power, thus being able to perform on mobile.

If this option is chosen, the system architecture will change and adapt accordingly. The system architecture will be as follows:

The KnightsShield will broadcast the video in real-time to the mobile. Upon receiving a frame, the machine learning system will feed the frame to the models then the Result Evaluator module will output if there is the existence of a drone in the frame. If there is a drone, it will also output the location of the drone in the frame. With this data, the user will be able to see a live broadcast of the KnightsShield and frames highlighting any drones in the broadcast.

DroneX

To deploy the machine learning system on an embedded system, we first need to train the model which can be done on a desktop. After training the model, the model will be deployed on the embedded system. This process is called inference.

Having the machine learning system deployed on the embedded system provides many advantages. The system is more reliable than relying on connecting to the cloud and maintaining a connection. The system also achieves low latency, which is desirable for our case. The only disadvantage for our case is whether the computational power is enough for our system. Since we need to keep in mind that the system needs to be on 24/7. Thus deploying machine learning on the embedded system may drain the battery.

Cloud

If it is unable to perform well on either mobile or KnightsShield, the cloud is the best option. With the cloud, we will be able to provide the system with a lot of computational power and modules to provide real-time broadcasts and classification of the KnightsShield. One of the options to deploy the machine learning system to the cloud is to use AWS Lambda, which is further discussed in section 6.3.4.

6.5.3 Mobile Application/Web Application

To access the data and the system, we will implement a mobile or web application. The user will have access to stream from KnightsShield through the normal and see what is going on at the moment. Alongside any detection that occurs while streaming, the display will change to indicate the detection. The user will also be able to see all the previous detections and the images or videos to display detection.

RESTful API

API means application programming interface. It is responsible for setting a bridge between the user interface and the server.

RESTful API is an application programming interface that follows the REST architecture style. These are the 6 guidelines of the REST:

1. Uniform Interface
2. Stateless
3. Layered System
4. Cacheable
5. Client-Server
6. Code on Demand

This will assist us in having a simple, lightweight, and fast API, which is essential for our system.

The user interface we chose for our project was a website as discussed. It has several key functions that we will highlight here. The website needed as discussed above to broadcast a livestream of what the camera was viewing at any given moment. Then if a drone was detected we wanted a recording of this drone incursion to be displayed on the left side of the website such that it could be verified by a user. We then wanted to also display all the stats of the detection on the bottom of the website to easily allow users to understand what was happening in any given recording. These stats are are confidence level max and min of the recording, the time and date of the recording as well as the percentage that a drone was detected in the recording. This percentage of recording was calculated by taking total frames and having it divide the frames of detection. Giving us a number for which a user can use to decide if the video should be kept or not. When broadcasting a live stream there is text instead of stats that state that the current video is indeed a livestream instead of a recording.

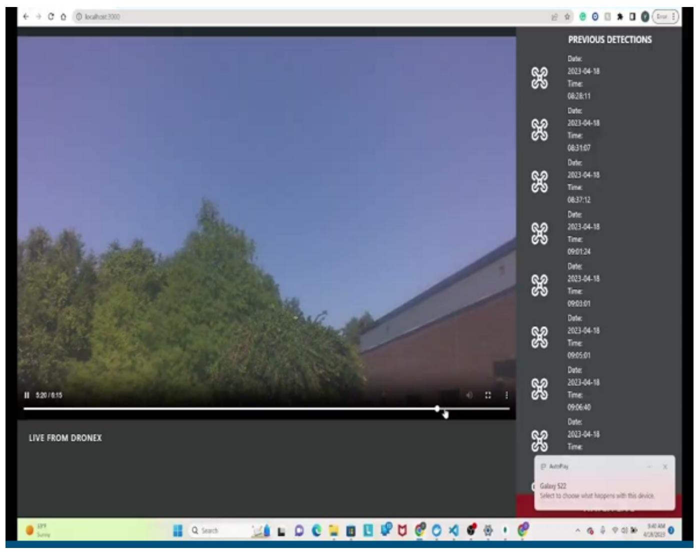


Figure 62: Final website broadcasting Live stream

6.5.4 Tools

To build an extensive system like this, a lot of tools will be required to focus on a specific task. These choices of these tools are made due to the fact that real-time detection and broadcast of the cameras of the device is needed. To achieve that, we need flexible, scalable, and lightweight tools.

Software	Description Summary
Git/GitHub	Version Control repository
React	Web UI Programming Framework

React Native	Mobile Programming Framework
Bootstrap	UI Framework
MySQL	Database
Google Drive/Google Drive API	Image Storage
AWS	Cloud computing platform
Node.js	Programming Language
Express.js	Framework for APIs
NGNIX	Web Server(Real-Time Messaging Protocol)

Figure 63: Figure showing the Data Flow Diagram of the DroneX System

React

React is an open-source front-end JavaScript library that builds user interfaces based on UI components. One of the main advantages of using React is the ability to create components and reuse them throughout the website. Another advantage is that React only re-renders the component whose value has changed instead of re-rendering the entire page.

An example of that is there is no need to re-render the navigation bar. Thus, it is only rendered once, and the body is the only thing being re-rendered. However, this also includes navigation between pages. Thus, a library called React Router is needed to achieve that. React Router is a library within React that enables navigation between views of various components.

React Native

React Native has the same exact features as React.js however it is used to build cross-platform(Android, Android TV, iOS, macOS, tvOS, Web, Windows, and UWP) mobile applications. It also allows developers to use native platform capabilities alongside the React Framework.

Similar to React, developers can create components and reuse them throughout the website. Also, the ability to re-render the component whose value has changed instead of re-rendering the entire page is also available in React Native.

Node. js

Node.js is an open-source backend Javascript runtime environment. It will be used to implement the backend and API. This will assist us in designing and deploying a flexible and scalable network application. It also provides low latency which is essential for our system.

Express. js

Express.js is a flexible and minimal framework that aims in building RESTful APIs, which are needed for our system. It helps to create a robust APU quickly and easily using the methods and middleware provided by express.

NGINX

NGINX is an open-source web server that could provide multiple services, including accelerating application and content delivery, mail proxy HTTP cache, and others. One of the important services that we will need in our system is RTMP, which stands for Real-Time Messaging Protocol, video stream. We will host an independent server hosted by NGINX that performs RTMP video streams. This will allow us to have a real-time broadcast of the KnightsShield and our mobile/web application will connect to the API to receive the broadcast transmitted from the KnightsShield.

MySQL

MySQL is a relational database management system which is developed by Oracle and based on SQL. We are choosing MySQL as our database is due to its flexibility and scalability, which essential to our project. We will be storing the information regarding the detections. However, the images will be stored on Google Drive and the link to the image will be stored in the MySQL database. This is due to the fact that MySQL cannot store images directly. Thus upon storing the information of the detection, we will use the Google Drive API to store the images in Google Drive and retrieve the link to the image then store the link.

AWS Amplify

AWS Amplify is a tool that allows users to build a full-stack website and mobile applications easily. It allows us to create a backend for our system alongside authentication and storage and build a UI using Figma and connect it to the backend without any need to code. It provides easy deployment and scalability for our full-stack system.

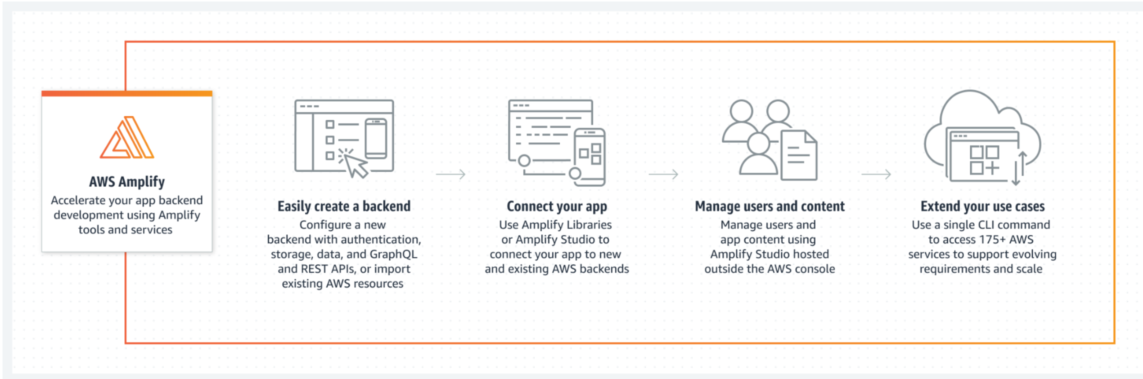


Figure 64: Figure showing the feature of AWS Amplify

AWS AppSync

AWS AppSync allows the user to create GraphQL and APIs through an endpoint to allow the user to query securely.

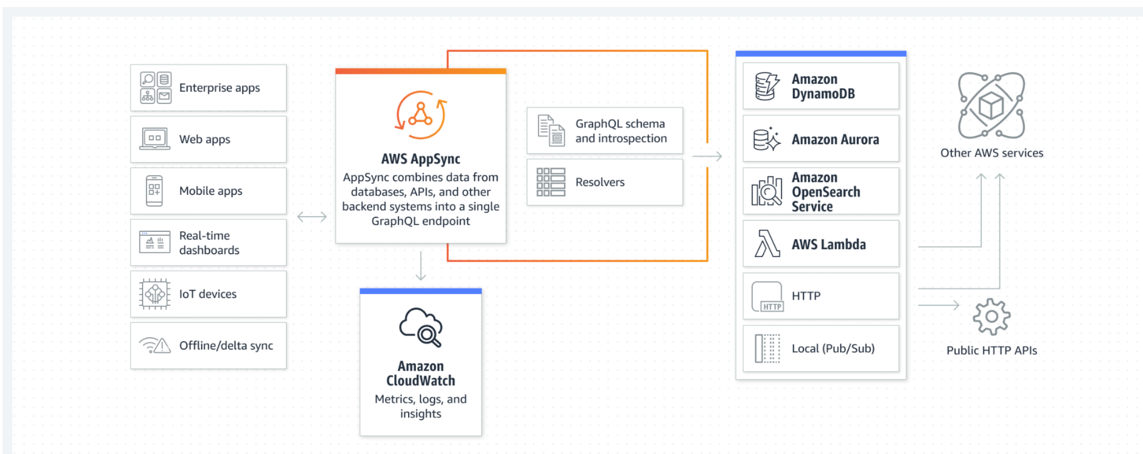


Figure 65: Figure showing feature of AWS AppSync

Amazon Rekognition

Amazon Rekognition is a service that allows you to automate image and video analysis using image processing and machine learning. It offers pre-trained image processing models that will assist in extracting information from video and images. It does not provide the exact models we need to build this system. However, we can use it for bird detection since we do not have a good dataset for it and other flying objects that may interfere with our drone detection model.

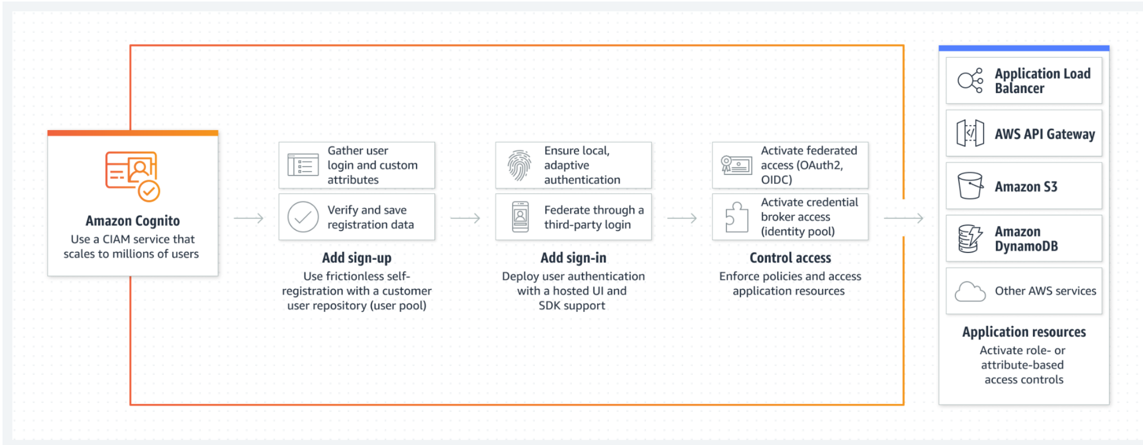


Figure 66: Figure showing feature of Amazon Rekognition

AWS Lambda

AWS Lambda is a serverless, event-driven compute service that allows running application or backend services like Stream processing, Web applications, IoT backends, and Mobile backends. Lambda will allow us to perform multiple things, including preprocessing the data before sending it to the Drone Detection module.

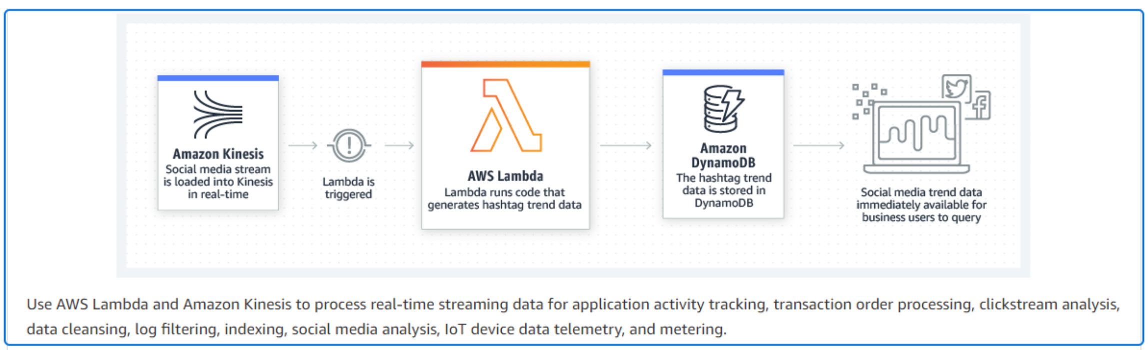


Figure 67: Figure showing feature of Amazon Lambda

6.6 Overall Design Summary

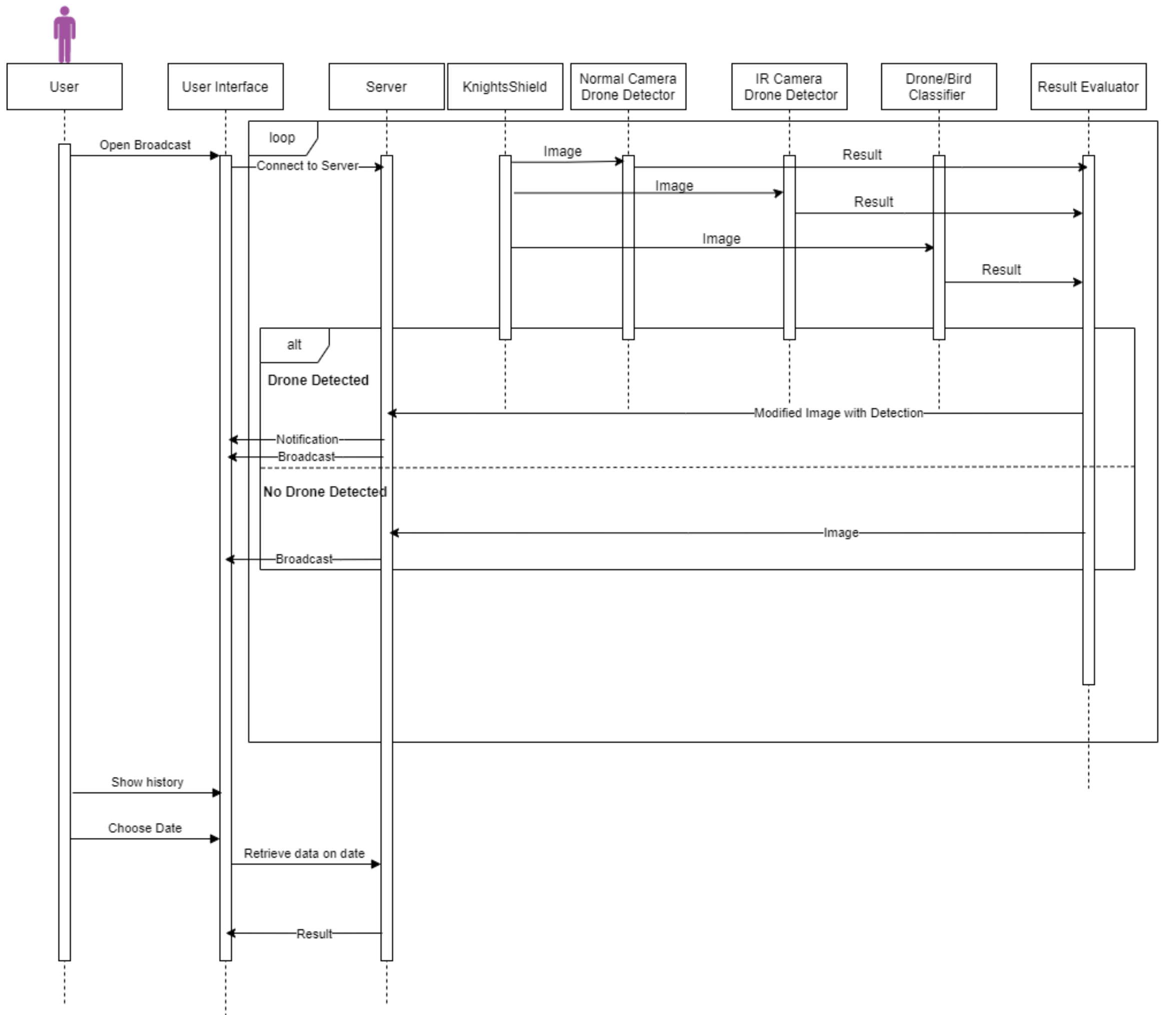


Figure 68: Figure showing the Sequence Diagram of the System

When the user connects to the system, the user has 2 options either to view the broadcast alongside the detection or see the history. The user will access the system either through a mobile application or a website.

View Broadcast Option

In this option, the user will have the ability to view a live broadcast of the KnightsShield. The user will be able to view the normal camera perspective and the IR camera perspective. In either option, the broadcast will first go to the server and will be sent from the KnightsShield. Afterward, the broadcast/image will be passed to normal camera drone detection, the IR camera drone detection, and the bird classifier. These models will all be ensemble in the result evaluator. Depending on the condition of the environment and results from the models, the evaluator will assign the appropriate weights for the results of the models and will calculate the final result, which will tell us whether there is a drone, bird, or nothing in the image.

The deployment location of the machine learning system is still undecided and is discussed in more detail in 6.3.2. After the machine learning system processes the image, if a drone is detected, the module will send the server the image, frame coordinate of the object, label, date, and time. Upon receiving this information, the server will save these data into the cloud to keep a history of the detections that occurred. The server will also either send a notification to the user if the user is not watching the broadcast.

However, if the user is watching the broadcast. The image will have to go through the machine learning system before being sent to the user, thus resulting in a slight delay which is dependent on the algorithms used in the models alongside the transmission delay, which is caused by the network.

Show History Option

In this option, the user will be able to see all the previous successful detections executed by the machine learning system. First, the user will see all the dates/times of the detections done. The will have to select the date and time that he wishes to see it. Upon selecting, the server will retrieve the data from the cloud and send it back to the user. The user will be able to see the IR camera view and normal camera view at the moment alongside the detection frame, which is a frame around the object detected, and its label. Also, it will provide all the results evaluated and the output of the models and result evaluator.

Backend Sequence

The server/backend will be running and will be receiving frames continuously from the KnightsShield. Upon receiving a frame, the frame will be fed to all the models. Then the models will output their results and will be fed to the result evaluator. The result evaluator will evaluate the label given the environment, time of the day, weather, and results from the models.

Upon receiving the result, if a drone is detected, then the image/frame will be edited with a box around the object. The edited image will be sent to the user to stream. At the same time, the image, edited image, labels, and result scores will be added to our database to keep track of the detections that have occurred.

However, if no drones were detected, then the image/frame will be sent directly to the user. The user will then be able to see a live broadcast with detections.

If a mobile application is to be developed, upon any detection, the server will send out a notification, notifying all users of the detection and label (Drone, Bird).

7 Prototyping

7.1 Printed Circuit Board

A PCB is a required part of our design. Understanding the details of how PCB functions is an important part of designing our PCB for the project. Many different parameters go into PCB that we discuss in the following sections.

When computers were first constructed, they took up massive rooms and could provide much less processing power than they could today. However, after decades of innovation and inventions we can now have smaller and more processing power. One such invention is the Printed Circuit Board (PCB). In appearance a PCB resembles a flat green board but under a microscope there is so much more detail. Printed circuit boards (PCB) are the foundational building block of most modern electronic devices. Whether simple single layered boards used in your garage door opener, to the six-layer board in your smartwatch, to a 60 layer, very high density and high-speed circuit boards used in super computers and servers, printed circuit boards are the foundation on which all the other electronic components are assembled onto.

7.1.1 PCB Function

Semiconductors, resistors, diodes, capacitors and radio devices are mounted to, and talk to one another through the PCB. PCBs are integral to almost every modern-day electrical system. A PCB allows seamless and streamlined communication between system components, effortless powering of circuits, and allows for a much more compact design for any electrical system need.

7.1.2 Our PCB Design

The PCB, or printed circuit board, is an important component for integrating our many device components into one system. PCBs are typically composed of flat laminated composite made from non-conductive substrate materials. The PCB will have layers of copper whose purpose is to connect the many components on the PCB. The PCB will include many parts, including the microcontroller and voltage converters. Our design requires us to provide power to both cameras, a GPS module, and a LoRa module. The specific modules have yet to be determined so we do not have a specific voltage value required yet. Most importantly the voltage is needed to power the microcontroller that we will soon decide upon. We will need an input port on the circuit board that allows the connection of the rechargeable battery.

Many steps have yet to be accomplished before we have our custom made circuit board. The first step is determining what specific components we will be using; once these decisions are made we can design our custom board. The software we plan on using for the creation of our circuit board is EAGLE. This is a software developed by Autodesk that provides schematic capture, PCB layout, auto-router and computer-aided manufacturing features. We have chosen this software because of the junior design providing the practice with this software. There were no other suggested softwares from the group for pcb design.

To create a PCB design in EAGLE there is a specific process to be followed. The first step is to create an electrical schematic, and to accomplish this we must retrieve footprints for necessary components, which means understanding the size and pattern of the component. Then we add the components to the schematic and connect them all together, meanwhile naming and labeling everything. Assign specific values to as many components as possible. Once these steps are complete we can execute the electrical rule check. An electrical rule check is a method used to check the robustness of a design considering both schematic and layout levels against various electronic design rules. The second step in creating a PCB design through EAGLE is to create the board layout. To do this, we arrange components in the best way possible, then run the ratsnest command. The ratsnest command assesses all of the connections in order to achieve the shortest possible paths. Then the final two steps are to route the parts then run the design rule check.

Once the PCB design is finished in Eagle, we will export the file as a "gerber" file. This is the most commonly used format for PCB manufacturing. Once we decide on a manufacturer the file will be sent to be printed. After we receive the custom made PCB board we can begin basic hardware testing.

7.2 Bill of Materials

The bill of materials for DroneX can be found in the figure below. The bill of materials will include the part name, part value, the quantity, the unit cost, and the total cost. The items included in the bill of materials will be all the components for the camera system. At the end of the bill of materials will be a generated total cost. Keep in mind the Bill of Materials has yet to be completed, as the design has not been finalized.

Part Name	Part Value	Library Part	Qty	Unit Cost	Cost
C1, C8, C9	TBD	C-US025-024X044	3		
C2, C5	0.1uF	C-EU075-052X106	2		
C3, C6	1uF	CPOL_US085CS-1AR	2		

C4, C7	10uF	CPOL_US085CS-1AR	2		
D 1-4	1N4004	1N4004	4		
D5	BAS70	BAS70	1		
IC1, IC2	LM317MBSTT3	LM317MBSTT3	2		
J1	B2B-PH-K-S(LF)(SN)	B2B-PH-K-S(LF)(SN)	1		
J2	n/a	JACK-PLUG0	1		
J3	USB4125-GF-A-0190	USB4125-GF-A-0190	1		
LED 1-3	LAP4-BOTTOM	LAP4-BOTTOM	3		
R 1-9	TBD	R-US_0204/2V	9		
R10	TBD	NTC640-9	1		
R11	240Ω	R-US_M0805	1		
R12	394Ω	R-US_M0805	1		
R13	240Ω	R-US_M0805	1		
R14	720Ω	R-US_M0805	1		
U1	MCP73871T-2CCI/ML	MCP73871T-2CCI/ML	1		
Total Cost					

Table 9: Current Bill of Materials

7.3 PCB Fabrication Services

Eagle has been chosen as our CAD development tool of choice. It is easy to work with and all members of the team has familiarity with its use. Once we have finished our schematic and board designs we will then take the generated gerber files and look for a manufacturer to produce our board. There are several that will adequately do the job for a good price point including SEEED, and Macrofab. However after looking at pricing and time for orders to be completed estimates we have chosen to use JLCPCB. This company is founded in Shenzhen China. Due to this large distance from the manufacturer and our current location of operation we will need to have a 2 week lead time for all manufacturing. The average price per board will be about 7-10 dollars but the real cost for manufacturing will also be found in shipping which can range from 20-40 dollars.

7.4 Facilities Used for Prototyping and Development

For our project, we will be utilizing the tools provided to us through the University of Central Florida. These tools include lab spaces, professors, etc. These tools will primarily be used when we are developing and prototyping our hardware. We have access to the UCF ECE Senior Design Lab which provides us access to a variety of critical tools for building and testing electronic circuits and hardware. The lab equipment consists of but is not limited to Oscilloscopes, Function generators, power supplies, resistors, capacitors, op-amps, etc. There are many important tools related to PCB assembly like solder and desoldering stations.

8 Testing

In such a complex project, it is important to have proper testing procedures and to have a plan for these procedures going forward. The hardware is a very sensitive area in terms of time management because ordering components takes time and if one gets damaged we need to know as soon as possible to order a replacement piece so we waste the least amount of time possible. Without proper testing, our system could be malfunctioning and we are left to guess what is wrong with the system. Instead of being careless we will properly test each and every aspect of the project therefore we can accurately diagnose what our problems are later down the road. The hardware must work as designed for the software aspect of the project to work. If the hardware aspect of the project is no good, then the two systems will not cooperate correctly. Without accurate data the entirety of the project becomes useless. Our test plans will detail the tools and methodologies used in testing major parts of the project.

8.1 Drone Detection Testing

Testing our drone detection system will require an open area, a drone, and a licensed drone pilot. Currently none of the engineers in the group are licensed to fly a drone. If none of the members of the project are able to obtain a drone license in time, we will find someone capable of flying one for us through the facebook drone groups near Orlando. Nicholas King has access to a drone, the drone is an Ares Ethos FPV Quadcopter RTF shown in the figure below. Once the group has access to a drone as well as a drone pilot, testing will take place at one of the recommended drone flying locations near UCF in Orlando, Florida.

Figure 69: Ares Ethos FPV Quadcopter RTF

To test our drone detection system we will place the camera system in a designated location where we will be able to detect drones. We will make sure our cameras can detect our drone specifically then fly our drone in predetermined areas. These locations will extend in all cardinal directions as well as varying the altitude of the drone. Once all directions of the drone from the perspective of the sensors are tested we will be able to pinpoint the boundaries of our system.

Drone detection testing will occur in many scenarios. The first scenario will be the middle of the day when there is bright and clear skies, this should prove to be the most effective environment for our cameras to detect drones. Next we will test our drone detection system at night when it is dark and the infrared camera will be doing most of the work. This is because the normal color spectrum camera will only see dark skies more than likely. Other scenarios we will be testing consist of cloudy and rainy environments. All weather scenarios must be tested to ensure our systems capabilities.

When we did test our drone detection system capabilities we found that testing in a rainy environment was not of interest for our project as we were unable to find a drone that could fly in such conditions. Thus we only tested the drone at varying distances from our camera against differing backgrounds such as wooded areas, buildings, clear skies, and cloudy skies. We also tested our systems ability to distinguish between other airborne objects such as birds, planes, and helicopters. In testing our drone detection system was found to be able to meet all of our engineering specifications.

8.2 Power System Testing

In this section, we will talk about the power system testing for the drone detection system. If the elements in our system do not have enough power or an unexpected power increase, some components might not function correctly or become damaged. If the component does not function correctly or any component gets damaged, we will need to replace it, which will require us to spend more money, so this project's overall goals will not happen. To achieve the goals we have for this project, we must test the power subsystems of the DroneX, and we must ensure that all the information is accurate. the way we will test the power system of our drone detection device is to monitor the voltage and current starting at the power sources and the load. When we did finally test the system we tested the PCB by itself first to make sure all of the voltage regulators output the correct value. When this was proven to be true we added Jetson Nano to the system and made sure it was receiving adequate power and current to operate without any worries of faults or breaking of the Jetson Nano.

8.2.1 Source Testing

The first test we will do is the source test When doing the source testing. We will first test the solar panel, which is responsible for keeping the battery charged by collecting energy from the sun during the day. We will test the solar panel by using the panel and a multimeter. Some of us would need to take the solar panel out on a sunny and overcast day and monitor the output voltages over seven or more hours. Testing the panel for several hours will provide us with an accurate and expected range for the primary source. it will also tell us if there is any problem with the panels and whether there is a low input voltage or high input voltage that will damage the device. Once we do all the solar panel testing and have all the information we need and it matches the expected input, we can continue testing other components within the subsystem.

After we test the solar. The next step would be to test the USB input. This part of the source testing would be easier than testing the solar panels because the USB input has a standard input. Any difference would indicate an unpredictable and unreliable element. There will not be any change in the power because the USB input will always stay the same, and if there is any change, that would indicate an unacceptable element. once the USB charger has been powered on, we will use a multimeter to monitor the connection for a few minutes to check the accuracy of the USB input. Once we test the USB input and verify that the USB input has the power input we were expecting, we will move on to the next phase of testing for the power system of DroneX.

8.2.2 IC Testing

After we test the source, we will now test the IC. To test the IC we will First monitor the readings at the input of the IC and monitor the output reading from the sources. Doing this will tell us if there is a change between the input and output voltages. Then we will observe the output voltage coming out of the IC. The input and output voltage will likely change. Next, we will observe the IC's output voltage when the solar panel input voltage changes. If the output voltage change by a substantial margin, then this would indicate that the IC is not working, and we would need to repair or replace it.

Next, we will test the functions of the IC. The battery is supposed to power up the IC when no other source is present, so when the USB input is disconnected and the solar panel is removed from all light sources IC is supposed to draw power from the battery. If the battery starts to power up the system, then we will confirm that this function of the IC is working. Then we will test to see if the IC will notice when the battery is low on charge, if the IC can identify a low battery then we will be able to confirm that this function of the IC is working.

8.2.3 Battery Testing

Next we will test the Battery. Before we can test the battery we must confirm that the output voltage of the IC is reliable, after we confirm that the IC output voltage is reliable, we will observe the activity of the battery and determine if there are any unexpected elements. To test the battery we will charge the battery with a 4 or 5 output voltage and during the charging process of the battery, we will observe the charge curve of the battery. if the battery is charging and discharging faster than we predicted then the battery could be damaged. Before we can use the battery we must observe a stable charge and discharge curve, once we have confirmed that the battery has a stable charge and discharge curve, then we can begin using the battery in our system. We will use a multimeter to test the battery, we will collect data to verify the charge and discharge curve. Once we can confirm that the battery can be able to get the right charge voltage, and the battery is discharged when the USB input and the solar panel are not connected to the battery or the IC, then we can confirm that the battery is functioning properly.

8.3 Printed Circuit Board Testing

Once we receive our custom made circuit board from the manufacturer we can begin testing and integrating the board with the rest of the system. To begin testing the PCB we must conduct a continuity test. This test requires the board to be disconnected from any power source or any other components; the test requires a multimeter to verify each connection on the board. For example, to confirm that a resistor is connected to a certain pin on the microcontroller properly, we use the multimeter. Once the multimeter has its pins across the connection you want to test, you must read the meter. If it shows a very small resistance, less than an ohm for example, then it is a solid connection. Every component must be tested this way. As well as the microcontroller pin connections to the pin headers. An extremely important continuity verification is confirming the ground connection between all components on the PCB. This includes making sure none of the nodes on the circuit board are shorted to ground.

After the continuity test is completed we must run a component value test to verify the validity of our circuit board. To complete the component value test we again use the multimeter to test the values of each RC component, resistors and capacitors, on the board. In the case that we need inductors on our circuit board we will not be able to test the values because the multimeter does not have the capability to do so.

Pending the success of the continuity and component value tests we will test the PCB with the power source. Our power source has yet to be decided but will likely be some sort of rechargeable lithium ion battery. When we apply the power to the circuit board we should be able to measure each of the pins on the pin headers. And lastly, we will be able to verify the system is receiving the correct amount of voltage from the battery(ies).

9 Administrative

In the Administrative section, we talk about the planning of our project. This includes items such as budgeting and project milestones. The budgeting and project milestones are some of the key objectives to any successful project, to ensure that the design stays within our desired cost range and the project is completed in time.

9.1 Estimated Budget

The tables below display the budget for each of the components of our project. The estimated budget shows the specific cost per unit, quantity, and total cost of each component for the project. One of the goals for this project is for the overall cost of the device to not exceed more than $300. Ideally, the finished product will fall within the estimated budget, like every other project we might have an unexpected price increase. The group is prepared for the cost to increase with all the unexpected that comes with the project.

Component	Cost per unit	Quantity	Total Cost
Microcontroller	$20	1	$20
Nvidia Jetson Nano	$167.39	1	$167.39
Color Spectrum Camera	$20	1	$20
Infrared Spectrum Camera	$50 - $100	1	$50-$100
PCB	$10	1	$10.00
Battery	$30	1	$30.00
Solar Panel	$35	1	$35.00
Power Subsystem Components	$10.00	1	$10.00
LoRa Module	$10.00	1	$10.00
GPS Module	$30.00	1	$30.00
MCP73871 Charge Controller	$5	1	$5
Total Cost			

Table 10: Current Budget

9.1.1 Final Budget Update

In the below figure you can see the total final budget that we had spent on our project. The first column consists of a variety of orders from companies such as mouser, digi-key, and newark. This section also consists of the PCB board orders and we had 3 different designs leading to an expensive project as a whole. The soldering equipment was a necessity and would have to be purchased again. The DroneX case parts are another cost that would remain the same. Of course as stated previously out of the three cameras we purchased we only utilized the 20 dollar one. The solar panel and battery were not implemented in our system. The machine learning cost was necessary, and finally the miscellaneous cost was for the lock for our locker in the senior design lab.

	Parts For PCB	Soldering Equipment	DroneX Case Parts	Cameras	Jetson	Solar Panel & Battery	ML	Misc.	Grand Total
	$9.62	$3.67	$42.79	$114	$149	$35	$100	$4.09	
	$10.69	$42.11	$3	$155	$20	$30	$250		
	$40.79	$8	$22	$20	$8				
	$28.99								
	$163								
	$180								
	$40								
	$255								
Totals:	**$728.09**	**$53.78**	**$67.79**	**$289**	**$177**	**$65**	**$350**	**$4.09**	**$1734.75**

Table 11:Final Budget

9.2 Milestones

In the tables below we describe the current milestone for the fall and spring semesters respectively. The full descriptions for the fall semester can be found in the table below, and the full description for the spring semester can be found in table 11. The goal for creating these milestones is to ensure that we stay on track as the semester progresses and that we don't Fall behind. Like most other projects, we will most likely need to add new milestones as we come across new challenges. In the first semester, we are going to do as much research and design as we can do, because doing a lot of research and design is an important part of our project, it also helps us detect anything that might cause crucial delays in senior design 2. A big part of this project is to figure out the right requirements and to make sure we understand the requirements we need. For the fall semester, we plan to acquire parts, Talk about different designs and potential features of the device, Finalize plans for desired device design, and Continue technology research to aid device design and build the foundation of the project report. We also begin designing the printing circuit boards for the power supply, and successfully completed and submitted the divide and conquer versions 1 & 2, 60-page report, 100-page report, and the final report. For the spring semester, we plan on designing the hardware section of the project and testing the system, Add Stretch Goal Features, creating the website for DroneX, Presenting the final project, and successfully completing and turning in the final report.

9.2.1 Fall Semester

Month	Progress Description
September	Begin to acquire parts. Talk of different designs and potential features of the device. Finalize plan for desired device design. Continue technology investigation to aid device design and build the foundation of the project report.
October	Research parts. Continue working on project report (60 pages due 11/4)
November	Finish 100 page report by 11/18.
December	Finalize final report due 12/6. Begin Eagle Printed Circuit Board design of power supply. Obtain PCB and finish build of device.

Table 12: Fall Semester Milestones

9.2.2 Spring Semester

Month	Progress Description
January	Design and Breadboard Test Hardware. Parts, PCB order confirmations. Test the System.
February	Test System.
March	Add Stretch Goal Features. Final Testing and System Revisions.
April	Create the DroneX Website. Present final project. Turn in the final report.

Table 13: Spring Semester Milestones

9.3 Project Management Tools

In a team environment it can sometimes be tricky organizing the team to get everyone to work together as a whole unit. Many tools were used to organize our ideas, set up meetings, and express our ideas. There were several in person meetings as well as online meetings. Some of the tools we used to work on this project are google docs, text group chats, groupme, zoom, and canvas. Google docs provided a platform for everyone to continuously work on our report all at once. Everyone could see what everyone else was doing so it prevented people from overlapping duties; it made it easy to work and easier to communicate. Next we used a cellular text group chat that was our main source of communication. While working on our report and research the main form of communication was through texting one another in a group chat that included all members. The texting group chat was also how we scheduled our in person meetings, which we almost always do at the library on UCF campus.

Groupme was another form of communication that the group exercised. This was used when someone needed to share a link with the team which would not be effective through the text group chat when wanting to open the link on a computer. For example, if we needed the link to a zoom meeting we would use groupme to achieve this goal. This leads right into the next management tool and arguably the most effective, Zoom. Zoom is a video communication application that allows us to meet face-to-face through our computer screens. Zoom was also extremely important when meeting with our professors Richie and Wei. In these meetings they provided us with vital information that helped guide us through the project. Zoom proved to be super helpful when we had instances where we could not meet in person. Some of these instances include bad weather, including two hurricanes this semester, someone was out of town, or on the road driving to or from work/school.

The last management tool, yet also the foundation of the class was canvas. Canvas provided a medium of communication for our SD1 professors to deliver information, assignments, feedback, etc. Canvas holds all of the files that helped guide us throughout the semester. It is also the website where we submit all of our work.

9.4 Parts Supplier

To achieve the goals we had for this project, we need to find a reliable supplier that can sell us all the required parts we need. We buy and order our parts from different suppliers to get the parts we need for the drone detection system. Before ordering any parts, we first research and find the parts we need for the project. Then for each of the parts, we find the datasheet about the specific part we selected for the project and see if it is the best choice and if that part has the requirements we need for the drone detection system. After getting enough information on the specific part and deciding that it has the requirements, we searched different websites for availability, price, and reliability. We want to buy from suppliers with the cheapest, most reliable components, and we want to be able to receive all the parts we need for the project early or on time so we can begin building and testing the system. The faster we get all the components we need for the drone detection system at the lowest price, the better it is for us to complete all the goals we have for this project. We chose to mainly use Digikey and Mouser as our suppliers of choice as they had low lead times and fairly cheap shipping. Both of these companies were also consistently stocked with the lowest prices for all the components we required to make this project a success.

10 Conclusion

The original goal of our project was to design a drone detection system that can detect a drone through cameras, both infrared and normal, and then through our machine learning software. This was not all accomplished as we had to scrap the IR camera as the technology was too expensive to include in our project effectively. The models we tried for the IR camera were not of the functionality we required only allowing for limited night vision in ideal circumstances. The project however, though very challenging, was as a whole a success. The system we created does detect drones at a high rate and not only broadcasts these detections live to our website but also records these detections when they occurred. The case we built met all engineering requirements we set forward at the onset of this project. It is a mobile device that can easily be transferable and is water resistant such that it can maintain existence in an outdoor environment.

This project was not without its own problems however as we faced a lot of adversity when designing and manufacturing this device. This was the first time many of us had tried to develop any kind of hardware device from scratch and the growing pains from a first time development environment were very apparent from the start of the project as we made many mistakes. One of the biggest mistakes we made was from our inexperience in soldering and construction of PCB parts. This led to the destruction of our EC25 module however we did not let this ruin our project. Switching our design from cellular to wifi centric such that it would still be functional at the end. There were many more instances like this the group went through but through each interaction we learned more and grew as engineers.

Growing as engineers was also present as we learned to work together as a team. The first semester of senior design 1 was a challenge for all of us as we were not adequately prepared for the work that was required as we lacked planning skills and management skills as a group. From this failure of management we learned from however and in senior design 2 we managed to meet all of our deadlines and effectively plan out our project such that when we did meet obstacles we had the time to make adjustments due to our planning as a whole.

Lastly we as a group were all very happy with how our project turned out as a whole. We would look to add a second IR camera in the future as well as add more functionality to the MCU that would help improve the user interface. This as well as adding a second form of detection such as audio or radio wave detection would also help make this project even better in the future.

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